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LICENTIATE THESIS

The automotive industry is rapidly developing driving automation systems with the aim of supporting drivers and enhancing safety through taking over parts of the driving task, such as controlling the speed and keeping distance to other vehicles or relieving the drivers from the driving task altogether, providing fully automated drive. With the development and integration of these technological systems into the car, the driving task becomes increasingly complex, presenting drivers with new challenges regarding their understanding of their responsibility and their cars' capabilities and limitations. Therefore, understanding more about people's use of driving automation systems, and the factors influencing how these systems are perceived are essential parts for designers in order to design through the lens of their users.

Findings from three research studies are presented, and results synthesized into an overview of factors influencing the driver's perception and consequent understanding of driving automation systems. It was found that the driver's understanding is shaped through different and individual experiences, which influence how the car's behaviours and responses to /something/ are interpreted and understood. Thus, when designing driving automation systems, designers have to bear in mind that there are factors that influence the driver's perception of the cars that go beyond the immediate interaction with the driving automation, in other words, the interaction with displays and controls. Amongst other factors, preconceptions and previous experiences, perceived usefulness, trust, system performance and driving behaviour shape how drivers perceive driving automation systems and their consequent understanding – perception creates reality.

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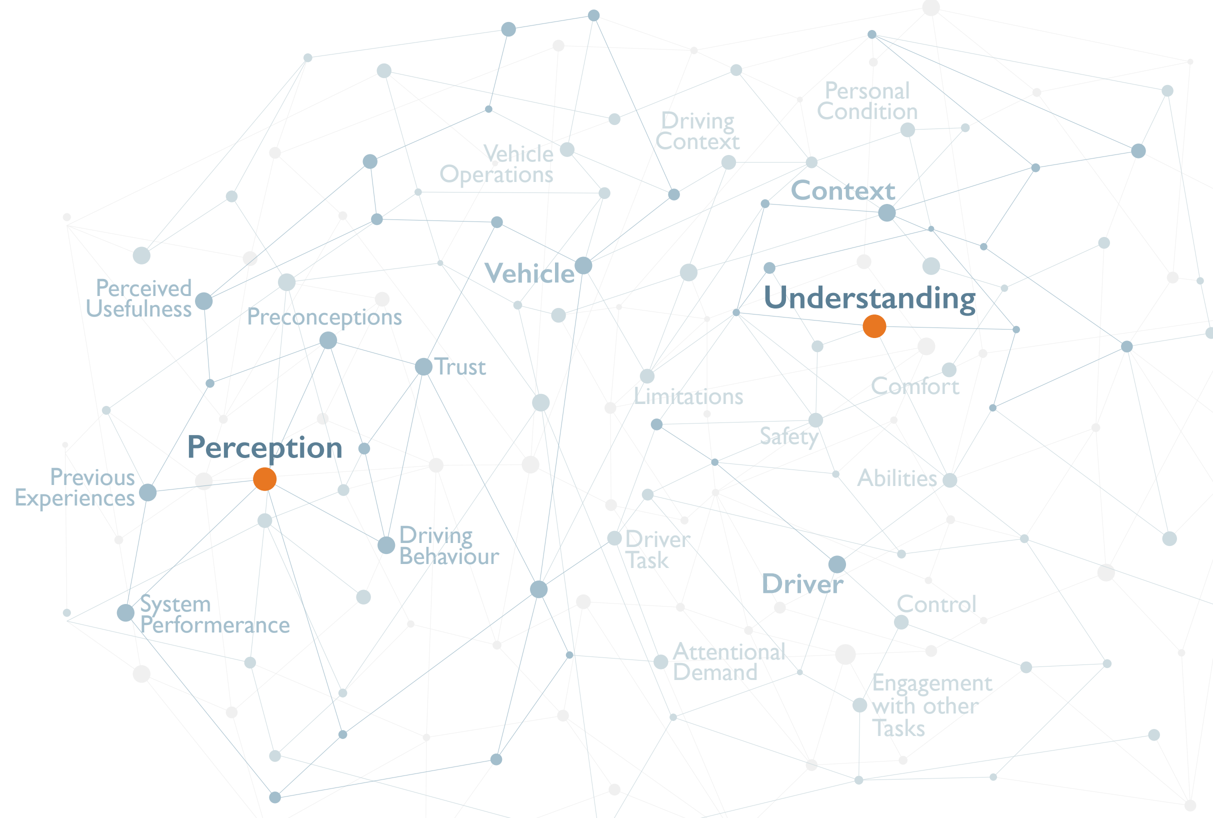
FJOLLË NOVAKAZI

Perception Creates Reality

2020



Perception Creates Reality

Factors influencing the driver's perception and consequent understanding of Driving Automation Systems

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020
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THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

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Department of Industrial and Materials Science
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Gothenburg, Sweden, 2020

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Factors influencing the driver's perception and consequent understanding of Driving Automation Systems

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Technical Report No. IMS-2020-10
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Cover by Johannes Nilsson

Printed by Chalmers Reproservice
Gothenburg, Sweden, November 2020

Abstract

The automotive industry is rapidly developing driving automation systems (DAS) with the aim of supporting drivers through automation of longitudinal and lateral vehicle control. As vehicle complexity increases, drivers' understanding of their responsibility and their vehicles' capabilities and limitations becomes significantly more important. In order to motivate manufacturers to adopt a human-centric perspective for the development of driving automation systems, the factors influencing the driver's perception during usage of such systems have to be understood. Therefore, the aim of this thesis is to contribute to the understanding of factors influencing user perception and understanding of driving automation systems in order to guide future design decisions from a human-centric perspective.

The research for this thesis is organised into three empirical studies, embedding a mixed-methods research design. Study 1 aimed at investigating usage of DAS during different driving situations by facilitating an online survey. Studies 2 and 3 aimed to explore how drivers motivate their usage of driving automation systems, and which factors affect their understanding. Study 2 adopted an Explanatory Sequential Mixed Methods approach, consisting of a Naturalistic Driving Study and in-depth interviews to elicit knowledge about how users understand the DAS, and which factors influence usage. In Study 3 observations and interviews during an on-road driving session with a Wizard-of-Oz vehicle were conducted to gain insights into how users build an understanding of a vehicle with multiple levels of automation.

The results show that the users of such systems, independent of the level of automation, talked about the systems by referring to different elements: the Context, the Vehicle, and the Driver. In addition, eleven recurring aspects describing the drivers' understanding of an automated system were discerned. Furthermore, six factors were identified that influence how drivers perceive driving automation during usage. The six factors are Preconceptions, Perceived Usefulness, Previous Experiences, Trust, System Performance, and Driving Behaviour of the Vehicle. Collectively, the identified aspects and factors constitute the building blocks of a process describing how drivers perceive driving automation systems and how this shapes their consequent understanding. The process is presented as a descriptive unified model.

The main contribution of this thesis is twofold: unification of aspects found to shape a driver's understanding of a driving automation system, and the presentation of a unified descriptive model of the process showing how this understanding is shaped through what the driver perceives at the moment of use.

Keywords: driving automation, automated vehicles, levels of automation, perception, information process, understanding, user perspective, empirical research, mixed-methods research.

Acknowledgments

"There are things known and things unknown and in between are the doors."

As I reach the first door on my journey, I look around and feel the need to thank a few persons who have guided me, collaborated with me, and supported me. Without you, no keys would have been obtained and no doors opened.

First and foremost, my deepest gratitude goes to MariAnne Karlsson, my principal supervisor who supported me throughout the process and beyond. I greatly appreciate you and your valuable comments and count myself very lucky to be able to pursue this path with your guidance. Lars-Ola Bligård, my co-supervisor, you are the biggest cheerleader and best support one could ask for. What would all the long hours be without our discussions – not as insightful and not as much fun. I am also very lucky to have Casper Wickman, Christoffer Kopp and Pernilla Krook who believe and trust in me - it means a lot.

They say that *"Women who wear black lead colorful lives."*, and isn't that just true, Helena Strömberg? Your visits are my favourite interruptions and inspirations. I'm always a little happier and a little smarter afterwards. Ultimately, *without black, no color has any depth. You know nothin'*, Göran Smith. And still there was always answers and good music. *To work by your side, was such a heavenly way to work.* Mikael Johansson, thanks for joining forces. *Together we can rule the galaxy!*

Special thanks go to all the participants in my studies, who dedicated their time and insights for many engaging and fun hours. A big 'Thank You' also to all my colleagues at Volvo Cars who showed interest and dedicated their time during my endeavours, providing practical and moral support. A big shout out further goes to the test drivers, Kaj Luukkonen and Claas Wedin, without whom Study 3 would not have been possible, or as much fun. And not to forget my co-authors and collaborators, who added that little extra fun, knowledge and growth to my work.Thanks to Ilya Meyer for proofreading all my papers and this thesis, and the pleasant communication throughout.
My warmest appreciation goes to my colleagues and friends at the Division Design and Human Factors. You are truly an outstanding bunch and it is a pleasure to learn with and from you; especially you Antonio Cobaleda Cordero, Anneli Selvefors, Maral Babapour, Cedrik Sjöblom and Siw Eriksson - thank you. Johannes. 'Thank You' for bearing with me and supporting me, by providing dinners, late-nights teas, much needed distractions, and most importantly your time.

Nënës dhe babait, faleminderit për dashninë dhe mbështetjen. Besimi i patundshëm në mua është dhurata më e mire që do të kisha kërkuar.

Appended Publications

Paper A
Karlsson, I.C.M and Novakazi, F. (2020). Drivers' usage of Advanced Driver Assistance Systems – An International Survey. *Manuscript submitted to the Journal Transportation Research Part F: Traffic Psychology and Behaviour.*
Novakazi and Karlsson designed the survey and collected the data. Analysis, writing and editing of the paper were carried out in collaboration between the authors.

Paper B
Orlovska, J., Novakazi, F., Bligård, L.O., Karlsson, M.C., Wickman, C., Söderberg, R. (2020). Effects of the driving context on the usage of Automated Driver Assistance Systems (ADAS) - Naturalistic Driving Study for ADAS evaluation, Transportation Research Interdisciplinary Perspectives, Volume 4, 100093, ISSN 2590-1982.
Novakazi planned and conducted the qualitative study phase. Analyses, writing and editing of the paper were carried out in collaboration between the authors.

Paper C
Novakazi, F., Orlovska, J., Bligård, L.O., Wickman, C. (2020). Stepping over the Threshold - Linking Understanding and Usage of Automated Driver Assistance Systems (ADAS). Transportation Research Interdisciplinary Perspectives, Volume 8, 100252, ISSN 2590-1982.
Novakazi planned and conducted the qualitative study phase. Analyses, writing and editing of the manuscript were carried out in collaboration between the authors.

Paper D
Novakazi, F., Johansson, M., Strömberg, H. and Karlsson, I.C.M. (2020). Levels of What? Investigating Drivers' Understanding of Different Levels of Automation in Vehicles. Journal of Cognitive Engineering and Decision Making. *Manuscript accepted with minor revisions.*
Novakazi and Johansson planned, conducted and analysed the study in collaboration. Novakazi and Johansson wrote the manuscript with feedback from the co-authors.

Paper E
Johansson, M. and Novakazi, F. (2020). To Drive or not to Drive – When Users Prefer to Use Automated Driving Systems. *[Submitted to 7th Humanist Conference but conference postponed until 2021].*
Novakazi and Johansson planned, conducted and analysed the study in collaboration. Johansson wrote the manuscript with feedback from Novakazi.

Paper F
Novakazi, F., Johansson, M., Erhardsson, G. and Lidander, L. (2020). Who's in Charge? The Influence of Perceived Control on Responsibility and Mode Awareness in Driving Automation. IT – Information Technology. De Gruyter Oldenbourg. *Manuscript accepted with minor revisions.*
Novakazi and Johansson planned and conducted the study in collaboration. Analysis was done by Erhardsson and Lidander with support from Novakazi and Johansson. Novakazi wrote the manuscript with feedback from the co-authors.

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CHAPTER I

Introduction

CHAPTER 1

Introduction

This thesis's introductory chapter describes the background and motivation for the development of driving automation systems, and the need for doing so with a human-centric perspective in order to enhance safe usage and positive user experience. Furthermore, the main research question is introduced, and the thesis structure briefly outlined at the end of the chapter.

1.1 Background

The number of road traffic accidents is one of the major issues in traffic safety research. According to estimated data 1.35 million road traffic deaths occur globally every year, and there is a rising trend (WHO, 2018). Identified reasons in traffic safety literature include driver inattention and distraction, aggressive driving behaviour and excessive speed, as well as performance errors (NHTSA, 2008), creating different initiatives and roadmaps striving for the goal of stabilizing and reducing the number of road traffic incidents. Two examples from a range of political and societal efforts are Vision Zero and Vision 2020. Vision Zero was launched by the Swedish government in 1997, stating that no one should be killed or injured in traffic. Vision 2020 was a vision set by Volvo Cars in 2008, with the aim that "nobody should be seriously injured or killed in a new Volvo car" (Volvo Car Corporation, 2019). Accordingly, automotive manufacturers have been rapidly developing driving automation technologies with the potential to fundamentally change road transportation and traffic safety for all road users. Elvik et al. (2009) distinguish between two categories to conceptualize safety technology systems: passive safety systems and active safety systems.

Passive safety systems aim to reduce the severity of injuries when accidents occur, using technologies such as airbags and seat belts. Active safety systems, however, aim to prevent accidents from happening through collision warning or driving support systems.

Driving automation systems can be viewed as a collection of active safety technologies whose aim is to support the driver. These systems are widely known as Automated Driver Assistance Systems (ADAS) or Driving Automation Systems (DAS). Even though these systems cannot completely prevent accidents, they have been shown to contribute to substantial reductions in the numbers of deaths and serious injuries (Cicchino, 2017a,b,c), which is why they are commonly regarded as solutions for addressing traffic safety problems (Gao et al., 2014; Kyriakidis et al., 2015; NHTSA, 2017).

While there still is considerable potential for these technologies to improve traffic safety and reduce collisions, it is important that driving automation systems are designed in such a way that drivers accept them, understand their capabilities and limitations, and use them appropriately, but do not misuse them or become over-reliant on them. Perceived usefulness, annoyance and trust can all affect whether or not a driver will be willing to use these systems. Many drivers, however, have misconceptions about the systems' capabilities and are unaware of system limitations. This in turn influences their experience of the systems, suggesting that driver understanding of the systems influences their interaction and, therefore, their degree of utilization (Llaneras, 2006; Jenness et al., 2008; Larsson, 2012; Choi et al., 2016; Viktorova and Sucha (2018); McDonald et al., 2018). Nevertheless, in many instances drivers tend to have higher expectations than the system limitations allow. These false expectations and subsequent over-confidence in the system can result in an increased collision risk. A study by Dickie and Boyle (2009) placed drivers into three groups regarding the limitations of Adaptive Cruise Control (ACC): aware, unaware and unsure. Drivers who were unaware or unsure of the system's limitations engaged more often in potentially hazardous behaviour, such as using ACC on curvy roads, than did those who were aware of the system's limitations. The same drivers who engaged in risky behaviour reported high levels of trust in the system.

Notably, in order for drivers to use the systems in a safe manner, they need to understand the different modes of operation as well as the limitations of the systems, or they will not be able to construct adequate usage strategies (Seppelt & Lee, 2007; Beggatio & Krems, 2013). However, various studies show that a large proportion of drivers are unaware of, or do not fully understand, the limitations of the systems fitted to their cars (Jenness et al., 2008; Larsson, 2012; McDonald et al., 2018; Boelhouwer et al., 2020). Critics argue that misconceptions and lack of understanding can be traced to the technological focus during development of these systems, concentrating on improvements in performance and the abilities of the automated functions (Yang et al., 2017; Jamieson & Skraaning, 2018). The main reason for this technology focus is that development is usually oriented towards taxonomies that describe the levels of automation and categorization of driving automation systems. One such example, and the most prominent one, is SAE's taxonomy J3016 (SAE, 2018), which aims to support a common understanding of automation levels and to provide a basis for regulation of automated vehicle technologies. Consequently, these taxonomies will affect how designers think and what decisions they will make during the development of driving automation systems, leading users to develop a faulty understanding of the systems' capabilities and limitations (Abraham et al., 2017; Smith, 2018; Seppelt et al., 2018).

All told, the interaction between driver and car must work satisfactorily if automation is to contribute to improved traffic safety and a positive user experience. Ultimately, a poorly designed system and a lack of understanding by the driver can lead to critical usage behaviour or even ignorance of the provided systems. Therefore, understanding of when the system can be used, how it works, and clear communication of the driver's responsibilities when engaging with driving automation systems, are all key factors that should be prioritized during the development of driving automation systems.

1.2 Aim and Research Question

This thesis has explored human-automation interaction[1] for driving with driving automation systems. The aim of this thesis is to contribute to the understanding of factors influencing user perception and understanding of driving automation systems, by answering the following research question:

RQ: Which factors influence the driver's perception and consequent understanding of driving automation systems?

In order to support a problem-solving approach and motivate manufacturers to adopt a human-centric perspective for the development of driving automation systems, the factors influencing the driver's perception during usage of such systems have to be understood. The intention is to generate an understanding that can guide future design decisions when developing automated vehicle technologies.

[1] Interaction refers to the use and control of the vehicle and the driving automation system

1.3 Thesis Structure

This thesis consists of 7 chapters, the contents of which are briefly described below.

Chapter 1 introduces the area of research by providing a short description of the background and problem area. Based on that, the aim and the research questions are presented. The chapter ends with a brief outline of the thesis structure.

Chapter 2 provides a brief description of the underlying frame of reference and relevant theoretical concepts for this work. It ends with the author's position regarding the research.

Chapter 3 presents the methodological research approach. The author's personal context and philosophical views on theories of science are presented, as well as the way this influences the methods chosen for handling the research questions. The methodological approach is laid out and finally, the procedure of the cross-study analysis is described.

Chapter 4 constructs the foundation for answering the assisting research questions. The answers are based on a summary of the studies that were conducted, and only relevant results are presented in the respective sections. Conclusions from the three studies are drawn at the end of the chapter.

Chapter 5 presents the cross-study analysis based on the findings presented in Chapter 4, aiming to address the research question. Further, it presents additional insights that emerged during the analysis, resulting in a unified descriptive model that clarifies the process whereby perception shapes the understanding of driving automation systems.

Chapter 6 concludes the thesis by discussing the results of the cross-study analysis and the theoretical and practical contributions made to research and development. Furthermore, reflections on the approach are made and future research areas are outlined.

Chapter 7 summarizes the conclusions of this thesis.

CHAPTER 2

Frame of Reference

CHAPTER 2

Frame of Reference

This chapter provides a brief description of the underlying theoretical foundation and the relevant concepts for this work. The chapter concludes with a contextual note.

2.1 Automation in the Automotive Context

Driving Automation Systems are designed to assist the driver and facilitate the usage of numerous comfort and safety functions (Spath et al., 2009). The functionality of these systems offers a range of assistive features such as anti-locking systems, blind spot warning, collision aid, and emergency brakes (Naranjo et al., 2003; Young, 2012; Bengler et al., 2014). Partially automated driving was introduced through the implementation of electronic brake and drive control. Partially automated driving functions support the driver with longitudinal and/or lateral control of the vehicle by scanning and analysing the environment (Brännström et al., 2014; Ziebinski et al., 2017). In order to support longitudinal vehicle motion (direction of travel) and lateral vehicle motion (position of vehicle in the lane) the DAS makes use of radar and camera technologies (see Figure 2.1). Longitudinal control was first introduced as Cruise Control, as a means of maintaining a selected speed over a long travel distance. This has come to be commonly known as Conventional Cruise Control (CCC), to distinguish it from Adaptive Cruise Control (ACC) systems which added forward-looking sensors to allow the system to detect and manage headway by detecting the distance and closing speed to a lead vehicle (Bengler et al., 2014, Sullivan et al., 2016).
Active lateral vehicle control is a development based on lane departure warning technologies, which detect when the vehicle crosses the road boundaries. However, systems supporting

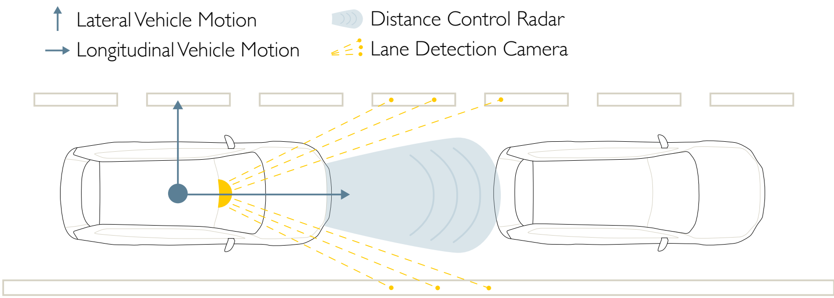

Figure 2.1: Simplified overview of DAS technology.

the active control of lane positioning are capable of steering the vehicle back into the centre of the lane instead of just warning the driver, as long as there are clear lane markings. Current versions of lateral vehicle control systems are variously named Lane Keeping Assist (LKA), Lane Centring Assist (LCA) or similar, depending on the manufacturer.
These technologies, however, come with limitations. The sensors, radars and cameras have limited capabilities regarding the degree to which they are able to detect small forward objects or lane boundary markings. Furthermore, most ACC systems do not detect forward objects that are moving slowly or are at a standstill ahead, and most lateral control systems are not sufficiently advanced to be able to steer around them. In bad weather conditions such as snow, rain, or fog, sensor and camera performance will deteriorate, reducing forward detection and lane detection capabilities. Likewise, on road types with many curves or complicated guiding patterns, the system is not able to process and execute the tasks correctly (Sullivan, et al., 2016). These limitations are a concern since drivers may not be fully aware of DAS capabilities and limitations and may therefore overestimate the system's ability to prevent collisions. Regardless of the challenges described, particularly in combination with ACC these systems are a step towards an automated driving experience (Trimble et al., 2014).

As a result, enhancements of current DAS are under continuous development. Automotive manufacturers are striving towards fully automated vehicles. The next stage will be systems offering automated driving under certain conditions such as traffic jam assistance, full lateral and longitudinal vehicle control at low speeds, or automated highway driving (Bengler et al., 2014). However, it is safe to say that users will face fragmented trips with regard to automation, where for the foreseeable future they will have different levels of automation available at different times depending on traffic, road or weather conditions and function availability.

2.1.1 Levels of Driving Automation

Fully automated vehicles (AVs) are predicted to be on the roads by 2050 (ERTRAC, 2019). Development on the way to a fully automated driving experience will be a gradual process, following the progressive implementation of DAS, which will prepare the ground until the successful introduction of AVs.

Several road and traffic organizations have attempted to develop and define taxonomies for levels of automation while driving. One of the widely acknowledged taxonomies was issued by the Society of Automotive Engineers (SAE). SAE's taxonomy was developed with the aim of classifying the different levels of automation in vehicles and creating a common understanding and basis for communication for the various stakeholders involved in the development. This classification entails six levels of driving automation, as illustrated in Figure 2.2.

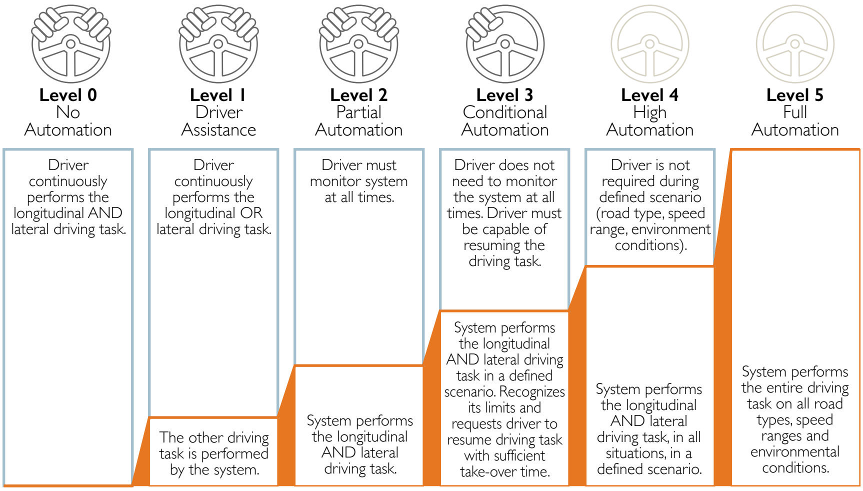

Figure 2.2: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (Adapted after SAE International, 2018).

This technical classification ranges between Level 0 'No Driving Automation' to Level 5 'Full Driving Automation', whereby each level describes different function allocations between driver and DAS, that is to say who is responsible for which task during the driving activity (SAE, 2018). The different levels are described as follows:

Level 0 'No Automation'
The vehicle does not have any assisted or automated driving technologies in place. The driver is expected to manually control the vehicle's longitudinal motion, that is to say maintaining its speed, accelerating and braking, as well as its lateral motion, in other words steering.

Level 1 'Driver Assistance'
The vehicle can assume either longitudinal or lateral control of the dynamic driving task. This automation level typically entails systems such as ACC, capable of maintaining an adequate distance to lead vehicles and adjusting vehicle speed. These systems are designed to assist the driver, but they are still required to be attentive and intervene. Nowadays ACC systems are offered by all automotive developers, often even as standard equipment in the vehicle.

Level 2 'Partial Automation'
The vehicle performs longitudinal and lateral control of the dynamic driving task through the combination of several assisted driving technologies, for instance Adaptive Cruise Control and Lane Keeping Assist. However, the driver is supposed to supervise and continuously monitor the system at all times and intervene when necessary. Several automotive brands already have Level 2 systems in place, such as Mercedes Benz Drive Pilot, Tesla Autopilot, and Volvo Pilot Assist. All these systems offer longitudinal and limited steering support, but usually require the driver to be hands-on-wheel and eyes-on-road at all times, otherwise the car will sound warning chimes and even deactivate the function (DeMuro, 2018).

Level 3 'Conditional Automation'
The vehicle assumes full longitudinal and lateral control under specific conditions. The system is able to make certain decisions without human intervention, while the driver is required to be on standby. The system is able to recognize its limits and requests the driver to take back control of the dynamic driving task if the required conditions are no longer met. Examples of an available conditional automation system on the market are Audi's AI Traffic Jam Pilot, which navigates through heavy and slow-moving traffic without the driver's attention (Volkswagen, 2019), and Cadillac's Super Cruise system which offers hands-free driving automation on mapped highways in the USA and Canada (DeMuro, 2018).

Level 4 'High Automation'
The vehicle assumes full longitudinal and lateral control of the dynamic driving task in a defined scenario, such as certain road types or traffic conditions. It does so at all times and does not need the driver to take back control while in the defined scenario. For example, the driver may control the vehicle in complex traffic situations, while the vehicle takes full control of the dynamic driving task when driving on the highway. While on the highway, human input is not required, and the vehicle is considered fully automated during that driving scenario. There are currently no highly automated systems on the market, although various automotive manufacturers such as Hyundai are successfully testing Level 4 vehicles on South Korean highways at speeds up to 110 km/h (Rivard, 2018).

Level 5 'Full Automation'
The vehicle performs the dynamic driving task independently of the driver, under all conditions and in different scenarios. To date, there are no fully automated vehicles on the market. Having said that, automotive developers are still racing towards full automation, aiming to offer transportation through all traffic and road situations without needing human involvement.

2.2 Challenges for the Design of Driving Automation Systems

The shift in control authority (Flemisch et al., 2012) when engaging with driving automation systems is known to have direct and indirect effects on driving behaviour. Direct effects are categorized as system function specifications that enhance performance on one or more control levels as intended by the system designers, for example improved lane keeping performance. Indirect effects are effects that are not intended by the designers and are thus not implied by the functional specifications. Nevertheless, these can result in Behavioural Adaptations (BA) of the driver to the system, mitigating potential safety impacts of these technologies (Sullivan et al., 2016). An OECD expert group defined behavioural adaptations as 'those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change' (OECD, 1990). The group concluded that 'behavioural adaptation does occur, although not consistently', and that it may be an immediate response to changes introduced or may only appear after a long time. Furthermore, it was established that BA generally does not eliminate the safety impact of DAS but tends to reduce the size of the expected safety effects. Manser et al. (2013) divide this adaptation into three temporal stages: immediate, i.e. initial experience; short-term, i.e. days or weeks; long-term, i.e. months or years. Most studies, however, concentrate on immediate or short-term effects and observe initial deviations from the mental model of the interaction with the DAS, leaving the long-term effects of these systems largely uncertain (Saad, 2007).

There is extensive literature on driver opinion and acceptance of driving automation. In particular, satisfaction and perceived usefulness of DAS are assessed through questionnaires and interview studies (e.g. Llaneras et al., 2006; Buckley et al., 2013; Eichelberger et al., 2014). Several empirical studies have been carried out to investigate different aspects such as age, gender, perceived effectiveness, usefulness, usability and ease of use, and learning (Wilson et al., 2007; Beggiato et al., 2013; Li et. al., 2015). Another stream of research on behavioural adaptation has developed a considerable body of literature on the identification of 'adverse behavioural consequences' (Grayson, 1996) or negative behavioural adaptations. Several studies suggest that driving with driving automation that takes over part of the driving task, such as maintaining speed and headway control, may reduce the driver's workload, which is a welcome side-effect (Stanton et al., 1997; Stanton & Young, 1998; Young & Stanton, 2004). However, many simulator and field studies suggest that this in turn invites the driver to divert attention to other things than the primary driving task, resulting in reduced situational awareness (Carsten et al., 2012; Llaneras et al., 2013). Moreover, a number of studies suggest that the driver's ability to understand the limitations of the driving automation, grasp its driving modes and maintain the correct level of engagement and interference in critical situations is a concern. These concerns are widely based on evidence about driver misconception of the relevant functions, or over-confidence in the systems' capabilities and limitations (Seppelt & Lee, 2007; Jenness et al., 2008; Larsson, 2012; Beggatio & Krems, 2013; McDonald et al., 2018).

As vehicle complexity increases through the introduction of multiple driving modes (i.e. levels of automation), communication between the driver and vehicle becomes significantly more important as new attentional demands and allocation strategies regarding responsi-

bility and control arise (Sarter & Woods, 1995; Flemisch et al., 2012).
Technological advances have led to different challenges regarding the development of driving automation systems. Lee and Seppelt (2009) have summarized the challenges of designing for driving automation and concluded that many issues arise during the early stages of development because of a technology-focused approach that disregards the human driver, who reacts to changes in feedback, task and task structure, and because of cognitive and emotional responses. These observations are also in line with Smith (2018) who found that established taxonomies categorizing the levels of automation (e.g. SAE, 2018), affect the way designers think and lead to design decisions based on technology-centred taxonomies, instead of user-centred perspectives, in other words taking user perception and understanding of driving automation systems into consideration. Furthermore, various research streams show that technology-driven taxonomies can affect the way users understand the systems, leading to an incorrect perception of their role and responsibility when engaging with a driving automation system (Abraham et al., 2017; Seppelt et al., 2018), potentially resulting in mode confusion (Sarter et al., 1997) and the misuse or disuse of such systems (Parasuraman, 1997).
While there is significant potential for driving automation systems to increase traffic safety and enhance comfort, the current challenges show that it is important that these systems are designed in such a way that drivers are supported in building a correct understanding of the system's abilities and limitations. With the rising complexity of driving automation systems and the continuous need for driver involvement throughout the various driving modes, designing clear communication of the driver's responsibility becomes significantly more important. In order to design driving automation systems that adequately support the driver in forming a correct understanding of the automated systems and their driving modes, as well as in building appropriate trust and usage strategies, it is necessary to understand both the process by which drivers understand a driving automation system and also the factors that influence their perception.

2.3 Perception

Our understanding of the world is based on the information we receive through our senses. This process of sensory experience is called perception. It involves recognizing environmental stimuli as well as acting in response to these stimuli.
Human perception is defined as "the process or result of becoming aware of objects, relationships, and events by means of the senses, which includes such activities as recognizing, observing, and discriminating" (APA Dictionary of Psychology, 2020a). Perception includes the five senses: Touch, Vision, Hearing, Smell and Taste. Beyond this, it includes what is known as proprioception, which is the ability to determine body movement and position, which supports spatial orientation without visual clues (APA Dictionary of Psychology, 2020c). Thus, perception is influenced by external factors such as motion, intensity, size, novelty and salience.Kenyon and Sen (2015) describe the perception process in three phases:

Step 1 "Attended Stimulus": the noticing of an environmental stimulus such as light, sound, taste, feel or any other stimuli from physical interaction with the environment. External factors will influence the stimuli on which one focuses one's attention.

Step 2 "Transduction": the organization of the stimulus and transmission to the brain, where it is structured into patterns. It also includes the cognitive process of recognition, which translates the received stimuli into a percept.

Step 3 "Recognition and Interpretation": the subjective interpretation of the percept, based on internal factors. Percepts are formed using multiple stimuli; alternatively, ambiguous stimuli can create multiple percepts.

Moreover, perception is influenced by internal factors such as motives, values, attitudes, past experiences and expectations (Kenyon & Sen, 2015). Similarly, the interpretation of an event or stimuli surrounding an individual is influenced by subconscious blinders, such as lack of awareness, and perceived similarities, all of which can cause errors in judgment. The recognition of an event and the subsequent actions, as well as the acquisition of knowledge, are outcomes of the perception process.
Additionally, expectation will create 'perceptual sets' which will govern choices between competing alternative activities, and therefore influence the perception process and its outcomes. Expectancy theory holds that a person will act in a certain way, based on their individual frame of reference, motives and interests. In other words, choices are made on the individual's estimate of how well the expected results of a given behaviour match with the desired results. Often, ambiguous information will be interpreted through an individual's perceptual sets to see or hear what they want to see or hear (Oliver, 1977).

2.3.1 Top-Down and Bottom-Up Processing

Building on the idea of Ken and Sen (2015) perception is developed through the lens of two simultaneous processes: a perceptually driven (bottom-up) process and a goal driven (top-down) process. Bottom-up processing is often referred to as data-driven processing, because it is assumed that perception is directly driven through the stimuli induced by the sensory system. Gibson first coined the term in 1972, stating that sensation is perception and that there is no need for processing the incoming information as it is analysed in one direction, in other words the raw data from our senses enables a direct interpretation of the environment. While Gibson followed a rather ecological view of perception, Gregory (1974) had a more constructivist take on the process of perception, arguing that perception is a constructive process relying on a top-down approach, based on higher cognitive information that harnesses previous experiences and knowledge. While initial standpoints suggested bottom-up and top-down processing as competing approaches, newer research suggests that they are indeed combined processes, emphasizing synchrony and attentional modulation based on the strength of the stimuli and given goals (Buschman & Miller, 2007; McKains & Kastner, 2010). This interpretation suggests that top-down and bottom-up processing happen simultaneously during the process of perception and that attention at a given time is guided by either of them, depending on the strength/relevance of the stimuli or the individual's goals. For example, when interacting with a machine interface, changes in focus of attention will be guided by the knowledge or expectations an individual has about where to find the sought-after information (top-down process), and/or from the inherent characteristic of the stimuli to trigger the shift in focus (bottom-up process). In other words, visual cues about the status of the driving automation system are sought in the instrument cluster, while an auditory cue connected to system status will direct attention there when needed. This process is also called 'apperception'; the combined perception through a bottom-up and top-down process of information (Saariluoma, 2003). The term more precisely refers to the process by which the content of information obtained from sensory processes is combined with the knowledge obtained from past experiences to form a mental representation of parameters such as, for example, interaction with a machine or product and its capabilities and limitations.

2.4 Author's Position Regarding the Research

While there are opposing views on the concept of perception, it is the author's belief that a unified view of the perception process is the answer to understanding the user's perception of a product. Similar to Saarilouma (2003) the author believes that the information users obtain during engagement with any product is received through a combined top-down and bottom-up process. Therefore, the author refers to the concept of perception as an integrated process between a top-down and bottom-up process, which leads to the development of a mental representation. This mental representation is referred to throughout this thesis as 'understanding'. Based on this background, Figure 2.3 exemplifies the author's position regarding how perception during usage is fed by a top-down and bottom-up process of information, that is to say perceptual sets and sensory input, and how this in turn influences the user's overall understanding of a product.

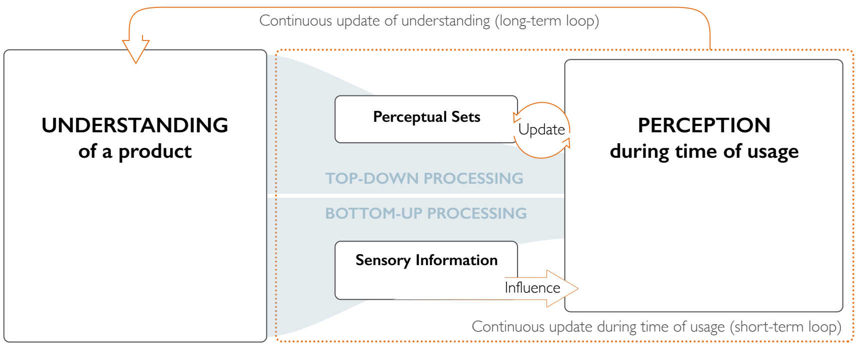

Figure 2.3: Process of perception through bottom-up and top-down processing of information.

CHAPTER 3

Research Approach

CHAPTER 3

Research Approach

This chapter presents the methodological research approach. The author's philosophical view on theories of science is presented, along with an examination of the way this influences the choices made regarding the chosen approach to the research question. The organization of the research and the procedure of the cross-study analysis are also described.

3.1 Scientific Perspectives

The overall research strategy in the presented work was an exploratory inductive approach. Using an inductive approach data is collected, hypotheses formed, and possible theories are developed based on the identified results (cf. Boyatzis, 1998).
This work is aligned with a pragmatic worldview, utilizing practical and outcome-oriented methods that are based on action, leading iteratively to further action, providing support to answer the research questions at hand. In other words, the pragmatism applied takes an explicitly value-oriented approach to this research (Johnson & Onwuegbuzie, 2004). Pragmatism recognizes that meaning exists within an object, as well as within a subject, meaning that our reality is constantly renegotiated, debated and interpreted in the light of its usefulness with regard to the scope of the issue. Consequently, knowledge is viewed as generalizable and contextually unique, and the nature of the acquired knowledge is best viewed in terms of its practical uses (Moon & Blackman, 2014). Hence, in this thesis knowledge means understanding which factors affect the user's perception of the driving automation, based on empirical findings gathered through the application of an embedded mixed-methods study design. As pragmatism accepts that the best method to acquire

knowledge is one that solves the problem, a mixture of qualitative and quantitative research has been implemented. Creswell and Plano Cark (2018) define mixed-methods research as a paradigm in which the investigators collect, analyse and integrate qualitative and quantitative methods within a study or programme of inquiry, for the purpose of depth and breadth of understanding. In detail, they describe the core characteristics of mixed-methods research as:

- Collecting and rigorously analysing both qualitative and quantitative data in response to research questions and hypotheses;
- Integrating or combining the two forms of data into the results;
- Organising these procedures into specific research designs that provide logic and procedures to conduct the research.

Qualitative approaches have a well-established methodology, ranging from interviews, over focus groups, to participant observations. One of the main advantages of qualitative research is that it helps obtain explanations about why different phenomena occur, what their nature is and how they can be described, as the nature of qualitative data usually is open-ended. With the help of qualitative methods, a deep and extensive evaluation of a product or system is possible. Participants are usually encouraged to freely express their opinions, which helps build a discussion and allows them to elaborate on what they mean. Furthermore, events can be observed as they occur in their natural context of use, through different techniques, without reducing the complexity of the system, processes or tasks that are of interest. This enables the researchers to gain deeper insights and target problems at their root cause instead of only working on mitigating symptoms. However, although there are clear advantages, qualitative research is time-consuming and does not allow for large numbers of participants (Creswell, 2014).
Quantitative research, on the other hand, focuses on measurements that test hypotheses, determine an outcome and generalize conclusions (Denzin and Lincoln, 2008). The results may produce valid and reliable data due to the possibility of regulating the measurements with the help of specifically created technical solutions. Quantitative data can be obtained by quantifying subjective user input taken from extended user surveys or by using an automated method of data collection. This approach makes it possible to collect larger samples compared to qualitative research. Quantitative methods are especially useful when a systematic, standardized measurement is needed that makes it possible to generalize the conclusions from quantitative studies (Rovai et al., 2013).
The combination and integration of the two approaches throughout a project is also called an embedded mixed-methods design, facilitating the triangulation of data throughout the overall design of the research process in order to achieve insights and develop theories that answer the research questions (Creswell, 2014). The inductive approach in combination with quantitative and qualitative methods enables the generalization of particular phenomena to probable hypotheses, on the basis of which one reaches understanding about the investigated scope and supports verification through triangulation of the data.

3.2 Methodological Approach

This work relies primarily on empirical research to answer the main research question. The empirical research of this thesis has been organized into three studies, Study 1, Study 2 and Study 3, and resulted in six appended publications, Paper A to Paper F, along with a unified descriptive model which more precisely answers the main research question. The following section explains the aim and approach of each study. An overview of the organization of research and the output is illustrated in Figure 3.1. The research question aimed to identify

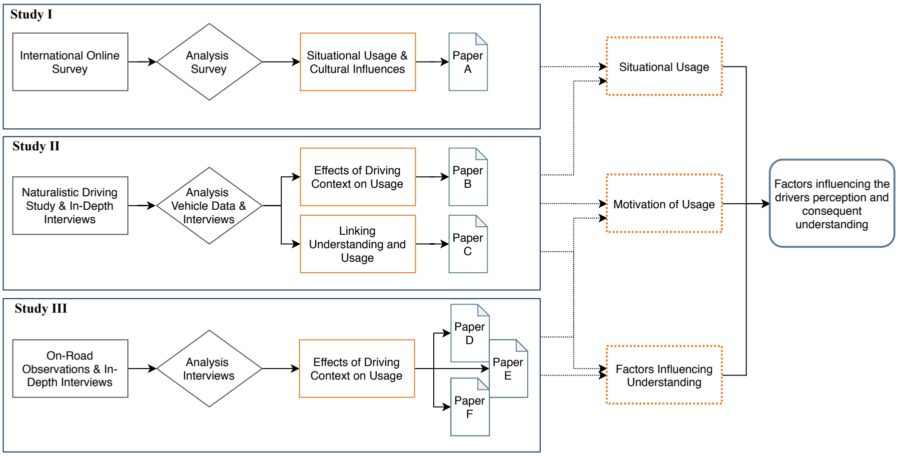

Figure 3.1: Organization of Research.

the factors influencing the driver's perception of driving automation systems. However, as a first step, it was important to determine if and when drivers use the systems. This was addressed in Study 1. In practice, Study 1 applied a quantitative online survey, reaching out to a large sample and various countries, aiming to gain an understanding about context-specific aspects of DAS usage. Several statistical analyses were carried out to evaluate the differences and commonalities between the investigated countries. The analyses specifically aimed to investigate the usage of two driving automation systems (Level 1 and Level 2) in different driving situations.

Having determined that there were differences in situational usage and seemingly a preference for the use of different systems for different situations, the next step was to find out how drivers motivate their usage strategies. Therefore, an investigation was carried out into how drivers explained their usage in order to identify which factors appear to influence driver understanding of the DAS. These questions were addressed in Study 2 and Study 3. Study 2 was separated into two parts, facilitating quantitative data collection through a Naturalistic Driving Study (NDS) to track driver behaviour and gain insights into how drivers use systems in their vehicles (Level 1 and Level 2). Sequentially, semi-structured in-depth interviews were conducted, which were partly based on the results of Study 1 and data collection from the preceding NDS, to elicit knowledge about how users understand the

DAS and which factors influence their usage. A thematic analysis was conducted, applying first a deductive coding approach (Hsieh & Shannon, 2005), in order to identify relevant themes. This was followed by an inductive coding approach (Boyatzis, 1998) in the next step, to discover new insights beyond the initial analysis, and this was a joint effort between the author and project partners. The results of the initial analysis were reported in Paper B and Paper C.

Study 3 utilized observations and in-depth pre- and post-interviews during an on-road driving session with a Wizard-of-Oz vehicle to gain insights into how users experience the use of, and how they build an understanding of, a vehicle with multiple levels of automation (Level 2 and Level 4). An analysis of the interviews was conducted to develop knowhow about the aspects that influence user understanding of the DAS. A thematic analysis was conducted using an inductive coding approach (Boyatzis, 1998) in order to explore how drivers understand a vehicle with multiple levels of automation. A more in-depth analysis was conducted in order to identify any difference in the description and understanding of the two modes of operation, which resulted in categorization of the identified aspects into three elements. These elements are Context, Vehicle and Driver, and they constitute three different layers which entail the drivers' understanding of the levels of automation. These results were reported in Paper D, and a conceptual model was proposed that explains which aspects users identify as relevant when making sense of a driving automation system. This model constitutes the basis for further work in this thesis and was developed in a joint effort between the author and co-researchers. Further collaborations with the same colleagues led to the results reported in Papers E and F, which elaborate on when drivers preferred to use a highly automated function, and how they understand their responsibility when interacting with a vehicle offering multiple modes of operation.

Table 3.1 provides an overview of the conducted studies, the methods of data collection and analysis, as well as the number of participants and the context in which the studies were conducted.

Table 3.1: Overview of Studies 1, 2 and 3.

	Method of Data Collection	Method of Data Analysis	Number of Participants	Context
Study 1	Online Survey	Descriptive Statistics with IBM SPSS 25.	Completed Questionnaires: 568 Germany; 532 Spain; 516 USA; 504 China	China, Germany, Spain, USA
Study 2	Naturalistic Driving Study data and semi-structured in-depth interviews	Identification of different usage patterns, with Microsoft Power BI. Deductive thematic coding approach for Interviews, with NVivo 12. Inductive analysis for integrated results of both sources.	Naturalistic Driving Study: 132 vehicles Interviews: 12 participants from identified usage groups	Sweden
Study 3	Observations and in-depth interviews	A thematic analysis using an inductive coding approach, with NVivo 12.	20 Participants	USA

3.3 Cross-Study Analysis

The empirical studies were followed by a cross-study analysis synthesizing the results from all three studies into a summary of factors influencing the driver's perception of a driving automation system. This analysis also resulted in a conceptual model designed to illustrate how perception during usage of driving automation systems shapes understanding of these systems.
The following sections describe the different phases of the analysis: 1. Separate thematic analyses of the three studies, 2. Cross-study analysis of the results from the studies, 3. In-depth cross-study analysis of the conclusions from the studies, 4. Iterative development of a unified descriptive model. Figure 3.2 illustrates the phases in an overview.

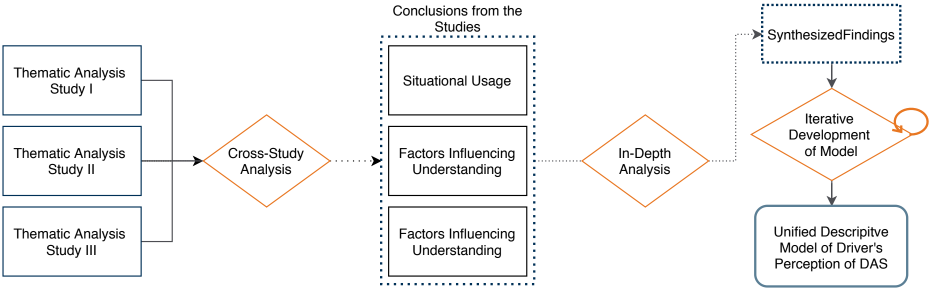

Figure 3.2: Overview of phases of the cross-study analysis.

Phase 1. To answer the main research question, the data from all empirical studies was examined in three separate analyses. In order to explore the aspects that describe the driver's understanding of driving automation systems and identify what factors influence their understanding, a thematic analysis was conducted using an inductive coding approach in all three studies.

Phase 2. After the thematic analysis of the three studies, a cross-study analysis was conducted on the identified themes. This cross-study analysis led, as a first step, to conclusions from the studies presented in Chapter 4.4. Conclusions From the Studies, answering the question of when drivers prefer to use driving automation systems, how they motivate their driving patterns and how they make sense of their interaction with the driving automation.

Phase 3. The conclusions from the studies were subjected to a more in-depth cross study analysis which resulted in a comprehensive overview of the findings, which are presented in Chapter 5.1. Synthesised Findings. The findings include 11 aspects and 22 sub-aspects constituting the drivers' understanding of a driving automation system. The identified aspects were split into sub-aspects and categorized into three elements: Context, Vehicle and Driver, which are part of a conceptual model developed during the analysis in Paper D. The previously developed model was extended with the new insights and used as a framework to incorporate the results from all three studies.

Furthermore, six factors were identified that did not fall into the categorization provided by this framework, nor did they explain how drivers understand the driving automation but rather how they influence the driver's perception of the driving automation. These six factors are: Preconceptions, Perceived Usefulness, Previous Experiences, Trust System Performance, and Driving Behaviour.

Phase 4. Based on the synthesised findings a conceptual model was developed which incorporated the six identified factors that influenced driver perception and clarified how driver understanding of driving automation is shaped through various factors. This was then continuously developed through an iterative process by conducting workshops with colleagues who are experts in this area and scrutinizing the iterated ideas in discussions and thought experiments. The result was a process incorporating the initially developed and enhanced model from Paper D on driver understanding, as well as a model describing the flow showing how user perception is influenced through a top-down and bottom-up process of information during usage, as presented and discussed in Chapter 2.4. Author's Position Regarding the Research.

These two models in combination answer the main research question that guides this thesis. The unified descriptive model is presented in detail in Chapter 5.2. The Process of How Perception Shapes Understanding and constitutes the contribution made in this work.

CHAPTER 4

Summary of Studies

CHAPTER 4

Summary of Studies

This chapter constructs the foundation for answering the research question. The results are based on three of the studies that were conducted. An overview of the key results is presented in each respective section. Conclusions from the three studies are drawn at the end of the chapter.

4.1 Study 1

The first study was exploratory in nature, focusing on the situational usage of driving automation systems. A scenario-based online survey was distributed to end-users in Germany, Spain, the USA and China and covered usage of Level 1 and Level 2 driving automation systems under different driving conditions.

4.1.1 Background and Aim

Different research streams indicate that both driving context and traffic environment play an important role in how drivers use driving automation systems (e.g. Viti et al., 2008; Pereira et al., 2015). However, although different studies on the usage and acceptance of Level 1 systems (i.e. ACC) were conducted, only a few studies have attempted to explore these factors for long-term users with access to vehicles featuring multiple systems, i.e. both Level 1 and Level 2. Therefore, the aim was to explore the usage of such systems in different contextual scenarios.

4.1.2 Data Collection

The survey was distributed in Germany (DE), Spain (ES), the (US) and China (CHN) to 2120 drivers and covered usage of and experience with Level 1 and Level 2 driving automation systems. The data was collected by means of an online questionnaire, set up with the LamaPoll survey tool, and was distributed via email with the help of a third party that had access to the various markets. The total number of questions was 36, and it took the participants between 10 and 15 minutes to complete the survey. Most of the questions consisted of Likert type (Likert, 1932) scenario-based statements with four response categories, without a neutral category. There were also a few rating scale questions, from negative to positive (1-5), and four open-ended questions, including one feedback question at the end of the survey. Additionally, the participant's background information such as age, gender, highest education level, and driving experience, if they drive for professional or non-professional reasons and their annual mileage behind the wheel, as well as region-specific driving contexts were mapped. The questionnaire was conducted in the official language of each country and translated by native speakers from the English version.

4.1.3 Participants

The sample strategy required that all participants hold a valid driver's license and that they are car owners or frequent users of car-sharing services. This was ensured via screening questions at the beginning of the questionnaire. Further, the aim was to obtain an equal distribution between genders and among different age groups. The detailed distribution of age, gender and other characteristics in the analysed sets can be seen in Table 4.1.

Table 4.1: Participants' Characteristics by Systems.

	Level 1 System (n= 549)		Level 2 System (n=159)	
Characteristics by groups	***n***	**%**	***n***	**%**
Gender				
Women	250	45.,5	71	44.7
Men	297	54.1	87	54.7
No Statement	1	0.2	1	0.6
Age				
< 20 years	3	0.5	1	0.6
21 – 30 years	105	19,1	44	27.7
31 – 40 years	194	35.3	72	45.3
41 – 50 years	103	18.8	21	13.2
51 – 65 years	88	16.0	11	6.9
> 65 years	56	10.2	10	6.3
Annual Mileage (km)				
Less than 5,000	54	9.8	8	5.0
5,001 – 10,000	104	18.9	22	13.8
10,001 – 20,000	141	25.7	51	32.1
20,001 – 30,000	72	13.1	36	22.6
More than 30,000	30	5.5	11	6.9
Driving Context				
Urban Area	79	14.4	25	15.7
Countryside	349	63.6	101	63.5
Expressways/Highways	120	21.9	32	20.1

The majority of participants reported an annual mileage between 5,001 and 20,000 kilometres, a smaller number between 20,001 and 30,000 kilometres, and a few less than 5,000 or more than 30,000 kilometres per year. Overall, the main driving context is countryside, followed by highways and lastly urbanized areas.

4.1.4 Analysis

After initial screening, invalid responses were removed due for instance to suspiciously short overall response time (< 300 s). Invalid values for the year of driving licence issue were removed, as were extreme outliers. Missing values were retained. In total 549 completed questionnaires for the Level 1 system and 159/footnoteSubset of 549, as all cars equipped with a Level 2 system will have a Level 1 system completed questionnaires for the Level 2 system were analysed using descriptive statistics. The analysis aimed to investigate usage of the two systems in different use situations (motorway, city driving, less dense traffic, dense traffic, in the dark, in the snow or rain, in slippery conditions, when tired and when driving is monotonous) through frequency distributions. The analysis resulted in a grouping of the situations into four different contextual factors: road types, traffic conditions, weather and daytime conditions and personal condition. Statistical analyses were conducted with IBM SPSS statistics software, version 25.

4.1.5 Key Findings

An investigation into how general demographic data such as age and gender correlated with usage of the Level 1 or Level 2 system showed no significant differences. However, a positive correlation was found between the mileage covered by the respondents and their general usage and attitude towards driving automation systems.

Context

Overall, the results show that users of Level 1 and Level 2 systems differentiate between different driving contexts when deciding which system to use. The contexts and differences in usage between the systems are described in the following paragraphs.

Road Types

A large proportion (68%) of the respondents reported that they most often or always used Level 2 systems on motorways, a slightly smaller proportion used the Level 1 system (59%). While showing similar tendencies regarding usage on motorways, in city traffic 42% reported never using the Level 1 system, but instead used Level 2 systems most often or always (60%) (see Figure 4.1).

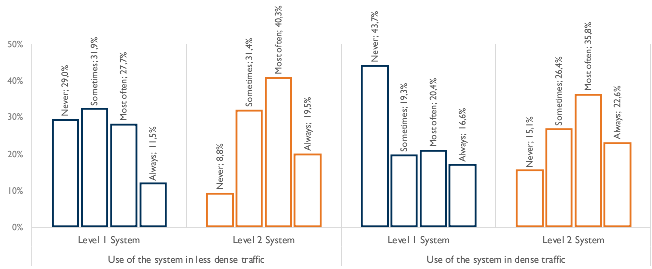

Figure 4.1: Usage of Level 1 and Level 2 systems on different road types in %.

Traffic Conditions

Regarding usage of the systems in different traffic conditions, a large proportion of the respondents (44%) stated that they never use Level 1 systems in dense or congested traffic, while Level 2 systems were used most often or always in the same conditions (59%). This trend shows also in the results for less dense traffic, where 40% most often used the Level 2 system and never (29%) used the Level 1 system. Here, the usage preferences for each system were largely the same when comparing between the two scenarios (see Figure 4.2).

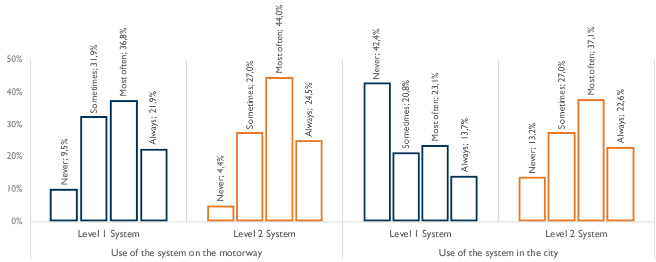

Figure 4.2: Usage of Level 1 and Level 2 system in different traffic conditions in %.

Weather and Daylight Conditions

When asked about usage in different weather conditions and time of day, 46% stated that they never use the Level 1 system in snow or heavy rain, but always (25%) or most often (30%) the Level 2 system, which is also the preferred system in the dark. Overall, there seems to be a preference towards the Level 2 system throughout the various conditions, as can be seen in Figure 4.3.

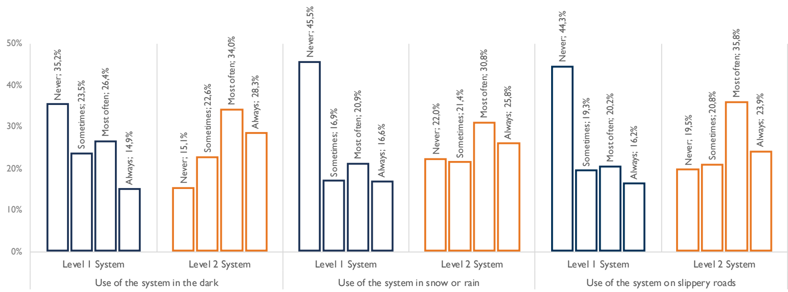

Figure 4.3: Usage of Level 1 and Level 2 system in different weather and daytime conditions in %.

Personal Condition

The results are similar when the driver's personal condition behind the wheel is taken into account. The respondents preferred to use the Level 2 system most often when they were tired (38%), and most often when driving gets monotonous (40%). Some however, stated that they used the Level 1 systems sometimes (28%) when tired, and most often (29%) when driving gets monotonous (see Figure 4.4).

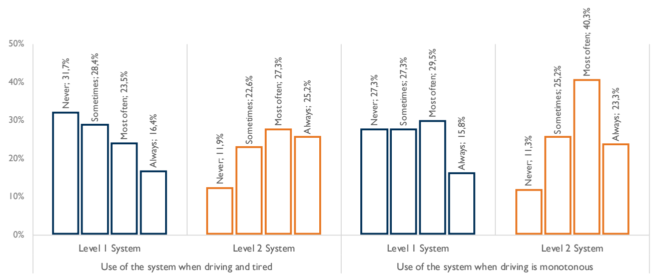

Figure 4.4: Usage of Level 1 and Level 2 system under different personal conditions in %.

Summary

In summary, the results show that usage of the systems was context-dependent, and that the systems were not used in the same way across the different contexts. The overall results indicate that the respondents had a slight preference for Level 2 systems. In varied traffic conditions there was a clear preference for the Level 2 system in both less dense and dense traffic situations. This result may be explained by the fact that the vehicles were equipped with both systems and the users could opt to use the Level 2 system, which includes all the capabilities of the Level 1 system with the addition of lane keeping support. The additional support function may also explain why the drivers reported higher usage of the Level 2 system when they were tired or when the driving was monotonous, as the system relieves them from some of the driving task. A similar observation can be made for driving in the city, where the respondents preferred the Level 2 system over the Level 1 system. When driving on the highway, however, both systems were used by the participants to a high degree which might be ascribed to the overall support the systems offer, for instance maintaining speed and keeping a safe distance to other vehicles. However, the results also show that in difficult weather conditions or in the dark, when visibility is poor, more users prefer to drive themselves and not leave the driving task to the automated systems. Under certain assumptions, this decision can be attributed to the limitations of the Level 2 system since it relies on visible lane markings and unrestricted sight for sensors and cameras, and also to a lack of driver confidence that the system is able to handle difficult weather and daytime situations.

4.2 Study 2

The second study was exploratory in nature and investigated the utilization of Level 1 and Level 2 automated systems through a sequential mixed-methods research design.

4.2.1 Background and Aim

In order for drivers to use driving automation systems safely and in such a way that they reap the benefits the systems provide, they need to understand the different modes of operation as well as the limitations of the systems, or they will not be able to build appropriate trust and adequate usage strategies (Seppelt et al., 2016). Therefore, the aim of this study was to investigate how drivers motivate their usage strategies and identify which factors influence their understanding of DAS, by triangulating data from a naturalistic driving (ND) study with explanations and reflections from in-depth interviews of selected participants.

4.2.2 Method

An Explanatory Sequential Mixed Methods (Creswell, 2014) design was adopted and modified to fit with the scope of this research. The sequential use of quantitative and qualitative methods (see Figure 4.5) aims to facilitate an integrated interpretation regarding the effect of driving perception on DAS usage. The study was separated into two parts. First, a

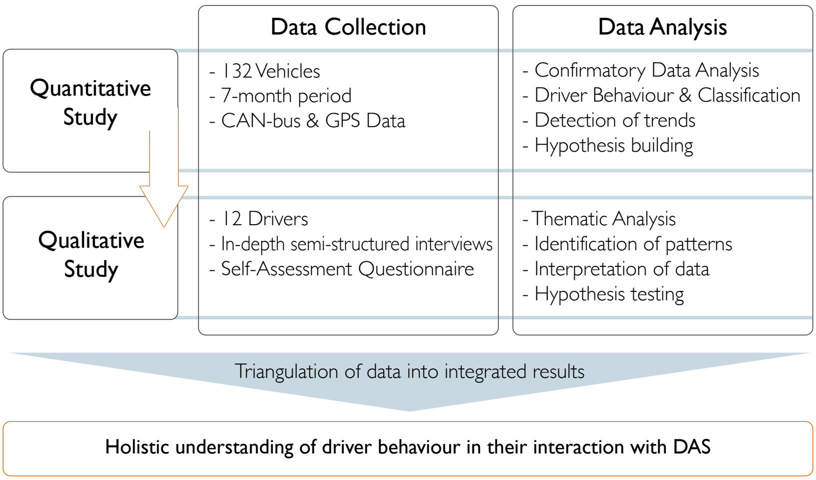

Figure 4.5: Explanatory Sequential Mixed-Methods Design.

naturalistic driving (ND) study was conducted, where sensory data from 132 Volvo vehicles was collected over seven months, from April 2018 to October 2018. Driving behaviour was

tracked and categorized to gain insights into the drivers' different usage patterns when engaging with Adaptive Cruise Control (ACC) and Pilot Assist (PA), the Level 2 system in Volvo cars.
In order to clarify the sensor-based findings, in-depth interviews were held with the study participants, with the aim of identifying the human factors impacting driver behaviour and system usage. The subsequent design of the qualitative phase was structured in such a way that it was based on the results of the quantitative data collection, with the aim of explaining the observed patterns. The investigation and validation of the quantitative data was done by means of in-depth semi-structured interviews to explore the individual experience and understanding of the systems. The qualitative study design is therefore based on clarification of the drivers' subjective reasoning in the detected target groups, in order to understand their specific usage patterns and so as to be able to map out the interdependencies that influence system usage.

4.2.3 Quantitative Study

The following section describes the study design, data collection method and analysis of the quantitative data collection phase.

Study Design

For the quantitative data collection, data from 132 vehicles equipped with the same system version of ACC and PA was collected and analysed. The data was collected through data acquisition systems which were installed in the test vehicles. These systems make it possible to keep track of the usage of the DAS, map-based positioning, mileage and uptime, while at the same time tracking contextual factors such as date of the event, vehicle speed, driving distance, time of day the activity occurred, GPS data, data for road condition identification, and other sensory data.

4.2.4 Data Analysis

For analysis of the quantitative data a deductive approach was adopted with the aim of clarifying the importance of the driving context for the usage of the DAS. The data analysis focused on four different parameters: 1. Single trip evaluation (investigation of unusual or interesting user behaviour), 2. Single-driver evaluation (focused on in-depth user behaviour evaluation of one specific case), 3. Group comparisons (comparison of driving behaviour between different groups), and 4. Overall assessment of the entire test pool. The quantitative analysis provided precise measurements of driver behaviour and system usage in various driving conditions, it identified different usage patterns regarding the evaluated functions and indicated some trends in driver behaviour. Data preparation, discovery and analysis were conducted using Microsoft Power BI.

4.2.5 Qualitative Study

The following section describes the study design, data collection and analysis of the qualitative data collection phase.

Study Design

The interview study was conducted between December 2018 and February 2019. The interview comprised four parts: Contextual Information; System Usage and Scenarios; Perception and Experience with the System; Information Display and Controls. A set of open-ended questions was accordingly developed, based on the four main themes. The structure of the interview and the interview questions were based on the initial results of the quantitative study. The interview was conducted using the developed topic guide, and all respondents were asked the same questions. However, the interview was not limited to the sample questions and the participants were encouraged to elaborate on their experiences and provide more descriptive insights. All interviews were audio-recorded with the participants' consent.
In addition, a questionnaire aimed at self-assessment for usage of the ACC and PA systems in different driving contexts was handed out to the participants after the interview. The questionnaire consisted of Likert-type (Likert, 1932) scenario-based statements with four response categories, without a neutral category. Finally, the participants' background information, including age, gender, car model and year, commute behaviour and annual driving mileage, was mapped. All the interviews were individual, conducted face to face and in English. Each session lasted about one hour, including interview and questionnaires. The participants were reimbursed with a cinema voucher for participating in the interview.

Participants

The interview study consisted of 12 participants, 2 female and 10 male, with an age range of 31-62 years (Mean 52.4, SD=9.0). The participants were recruited via an email newsletter directed only at members of the vehicle fleet that was analysed in the ND study. Therefore, the criteria for inclusion in the study were set through participation in the fleet. Thus, every interested member located in the Gothenburg area was potentially a valid participant. All participants commuted every day, with 5 participants accounting for an annual mileage of more than 30,000 km, 4 participants driving between 20,001 km and 30,000 km per year, and 3 covering between 10,001 km and 20,000 km. All the participants were long-term users of Volvo vehicles. According to their own estimates 9 of the participants were the sole or main drivers, sharing the vehicle only 0-10% of the total driving time. Two drivers shared their respective vehicles up to 20% of the time, and one driver up to 35% of the total driving time. All participants were Volvo Cars employees, but none of the participants who were involved in development of the functions were accepted for the interview study.

Data Analysis

Since the interview structure and content were based on the initial results of the quantitative analysis, in a first step a deductive thematic coding approach was applied (Braun & Clarke, 2006). After initial coding of one of the interviews, the codes were revisited, refined and validated by all the participating researchers in order to create a code book. In the next step the codes were collated into themes, during which statements regarding the two systems were highlighted. Lastly, the themes were revisited to examine the validity of the individual themes in relation to the data set and the trends observed during the quantitative data analysis. All interviews were carefully transcribed verbatim, coded and analysed.

4.2.6 Integrated Analysis

During the integrated analysis a hybrid (deductive and inductive) approach was applied in order to discover interrelations with the predetermined results and patterns observed in the quantitative data evaluation. After deductive thematic analysis of the interviews, the quantitative analysis results and identified relevant aspects influencing driver usage of the ACC and PA systems were revisited in order to find explanations for the trends observed in the data. This sought to investigate if the identified trends in the qualitative study were supported by the qualitative data. An inductive approach (Boyatzis, 1998) was applied in the next step to further explore the themes and discover new insights beyond the quantitative results that were not covered by the initial analysis. The analysis resulted in identification of the following themes that explained driver motivation to use the DAS and aspects relating to their understanding: Context, Perceived Usefulness, Preconceptions, Perceived Control and System Performance, and Trust.

4.2.7 Key Findings

The key findings of this study concentrate on insights into how users motivate their usage of driving automation systems, and what factors influence their understanding of the systems.

Context

In a first step the level of ACC and PA usage was assessed through the data gathered during the ND study. The single-driver evaluation showed that there are drivers who use the systems very little or not at all, and there are those who use the systems to a great extent. Even though significant differences in usage of the systems could be observed from the data, it could also be confirmed that the weather and geographical area were the same for all drivers, since the measurements were taken on the same dates and in the same region. However, the factors that varied were the road and traffic conditions. It therefore became clear that the driving context, especially road and traffic conditions, influence usage. After the interviews, all participants were asked to fill out a short survey which was a self-assessment of their usage of the two systems in different situations so as to follow up on these results. Similar to the results of Study 1, the self-assessment questionnaire resulted in clear preferences for different situations, as well as preferences between the systems for the different situations.

From the interviews, a consensus among the respondents was found on the advantages of using the systems during long drives (distances longer than 50 kilometres), compared to short drives, where most drivers tended to not use the systems at all. ACC in particular was mentioned throughout the interviews as a great support during long drives for maintaining speed and for offering extra safety and improved comfort. This shows that the journey's length was an important factor in usage of the systems, and an explanation of the preference for highways compared to city driving (something that was also evident in Study 1). Another stated reason for this was that in more urbanized areas frequent braking and driver engagement are needed due to the infrastructure or other traffic participants requiring the driver to activate and deactivate the systems very (or too) frequently. With regard to traffic conditions, however, the findings revealed that many respondents preferred to use PA in queuing situations, or at lower speeds, since the steering support was described as more stable. Furthermore, country roads were considered unsuitable for system activation. The respondents explained that country roads often do not have clear lane markings, resulting in the system jumping between active and stand-by, which is also the case during bad weather or in poor light conditions. For example, respondents said that the systems do not work as well when it is "pretty dark and rainy". Under more extreme conditions, like "when it is snowy and the car gets really dirty and sensors get blocked [. . .]" the systems might not even work at all, so the participants had learned not to engage the systems during those times either but instead drive themselves.

Preconceptions

The interviews indicated that preconceptions about the systems influenced the learning experience and the way the users' mental representation of their capabilities and limitations evolved. This assumption is also supported by the expectations the participants expressed about the systems before the first usage. When asked what was expected from the system, the answers varied between assistive convenience and safety systems, to more sophisticated systems that offered advanced driving support, for instance taking over the driving task for a certain amount of time. Depending on the expectations the drivers had beforehand, and the experiences gained during usage, the result was either disappointing or a positive surprise. These expectations played an important role in how the systems were perceived. Moreover, the drivers' statements indicate that there is a difference between what the drivers expect the system to be able to do, and what it is actually capable of doing. For example, the system does not have any kind of situational awareness, but the drivers seemed to expect a system that acts smarter and reads the current traffic situation, for example the status of traffic lights or the behaviour of other traffic participants. However, some participants were more cautious, explaining that they did not know what exactly to expect, so their overall experience turned out to be very positive. Overall, it appeared that those whose expectations were met, or even exceeded, seemed to have a lower threshold when testing and figuring out how to use the systems, and therefore engaged with them in ways that led to higher usage. Users who initially had high expectations of the systems ended up disappointed and refrained from using them.

Perceived Usefulness

Overall, all drivers agreed that both driving automation systems were useful and ascribed different values to them. The systems were consistently regarded as providing comfort and support, especially with simple tasks such as accelerating, braking and keeping a safe distance or keeping within the speed limit. This was frequently mentioned in connection with long-distance trips and monotonous driving activities on the highway. Because of the enhanced comfort, all drivers expressed more relaxation while driving and even calmer driving behaviour. All respondents stated that while using the system, they tended to follow the traffic flow rather than overtaking and choosing their own speed, which resulted in less aggressive driving, and this was also perceived as safer. Safety was a value the respondents frequently highlighted. For example, the participants claimed to feel safer when concentrating on a phone call or when they were tired while driving with PA as a support, as it was perceived as an additional pair of eyes or quick reflexes that provided support in situations where they themselves were not sufficiently attentive.

Perceived System Performance and Control

The perceived system performance emerged as an important factor in the decision about whether and when to use the driving automation systems. For example, the steering support provided by PA was not regarded as stable by most drivers, so they were more reluctant to engage with it. Other comments related to the time gap interval for ACC, which for many respondents seemed to be too long and invited other traffic participants to cut in front of their vehicle, especially in congested traffic. This was perceived as a very disruptive experience and led the drivers to override the system or deactivate it completely and drive themselves in such situations.

Regarding the different usage patterns that were observed for the different driving contexts, one factor that seemed to be discussed throughout was the control the drivers perceived to have when driving with an active system. For example in fluctuating traffic conditions, when there were a lot of vehicles on the road, participants explained that they preferred to drive themselves, indicating that they prefer to have control over the entire driving task in more demanding traffic situations. In contrast, others felt that the system taking over parts of the driving task relieved them in such situations. These contrasting statements show that the perceived control influenced the way the drivers understood their authority over the system. For some it seems that the advanced support implies they cannot intervene anymore, while others are aware that they need to be engaged at all times and ready to intervene, but still value the extra support they are getting.

The overall findings lead to the conclusion that system performance affects how much control the drivers perceive they have over the system, and therefore indicates how they understand their responsibility over the driving task as well as their acceptance and willingness to use the systems.

Trust

When the respondents were asked to describe their trust in the systems, one of the most important factors mentioned was the consistency they experienced during usage of the system. The drivers mentioned different reasons, some of them relating to system performance. More specifically, examples were given where the functions did not act as expected, which put the drivers into uncomfortable situations. Even though most drivers described the system as a support function, they still expected the driving aid to have the same abilities as human drivers and to be responsive to different situations at all times. This shows that some drivers have excessive trust in the systems' capabilities. Furthermore, the respondents stated that they had to build trust in the system over time. There seems to be a learning phase during which the user either builds enough trust to accept the system performance for what it is, and use the system, or the user experiences too many negative situations or inconsistencies they cannot explain and they never reach a state of acceptance, and therefore refrain from using the system. Furthermore, the respondents also mentioned that they differentiated between different situations and conditions regarding how much they trust in the system. The respondents explained that depending on road types or weather and light conditions, they chose which function to use or whether to drive themselves. This leads to the assumption that the better the user understands the system's capabilities and limitations, the better their expectations are met, and trust can be developed under these specific terms.

4.3 Study 3

The third study aimed to evaluate user understanding of and interaction with a driving automation system that offers multiple modes of operation, particularly focusing on a Level 2 partial automation function and a Level 4 high automation function.

4.3.1 Background and Aim

As the driving task is increasingly shared between driver and vehicle, the driver can end up in situations where the system mode is falsely interpreted, leading to erroneous actions and mode confusion (Sarter et al., 1997). One reason for confusion over automation levels and modes of interaction may be that the relationship and allocation of responsibility between human and automation system are not clearly understood by the driver. Therefore, the aim of this study was to investigate how drivers understand vehicles with multiple modes of operation, by eliciting insights from an empirical on-road observation study where the participants experienced two different driving automation systems, a Level 2 partial automation system and a Level 4 high automation system.

4.3.2 Method

An empirical on-road study took place in the San Francisco Bay Area, USA in June 2019. In the study the participants experienced two different modes (levels of automation), a Level 2 partial automation system and a Level 4 high automation system (SAE, 2018), in a Wizard-of-Oz (WOz) vehicle.

Equipment

In order to simulate a realistic use experience for the participants and to be able to test two levels of automation a WOz setup was facilitated. The test vehicle was a modified Volvo XC90 equipped with a Level 2 system, and the Level 4 system was simulated via a test driver who could take over control of the vehicle. The vehicle was modified according to all relevant road permission standards and approved for road testing by the local authorities, which enabled testing in a real driving context.
The prototype offered two modes of operation, defined as Level 2 partial automation and Level 4 high automation according to the SAE (2018) standard. The Level 2 system was always available and supported the driver in maintaining speed, automatically adjusting road speed with regard to other cars in front, and lane keeping assist. The Level 4 system was only operational in dense traffic conditions. When these conditions were met, the system would suggest to the driver that it could take over, allowing the driver to perform other tasks. When the conditions were no longer met, the driver was asked to take back control.

Procedure

Before the driving session, the participants were introduced to the study and gave their informed consent in accordance with the General Data Protection Regulations (GDPR). The

participants were interviewed before the drive regarding their expectations of vehicles with highly automated systems and received written and verbal information about the vehicle's two modes of operation, with an explanation of each respective system's capabilities and how to interact with them.
The driving session took approximately 90 minutes and included highways and urban areas in the San Francisco Bay area (Figure 4.6), in California, USA, during which the participants were encouraged to try out the functions as much as they wanted. All drives were conducted during rush hour, either in the morning or evening.
After the driving session, the participants were interviewed with special focus on how they understood the two different driving modes they had experienced. They were also asked to describe the Level 1 and Level 2 systems in order to identify factors that seem relevant to their understanding of the systems. Afterwards, the participants were informed that the Level 4 system was simulated. All interviews were audio- and video-recorded with informed consent by the participants and later transcribed.

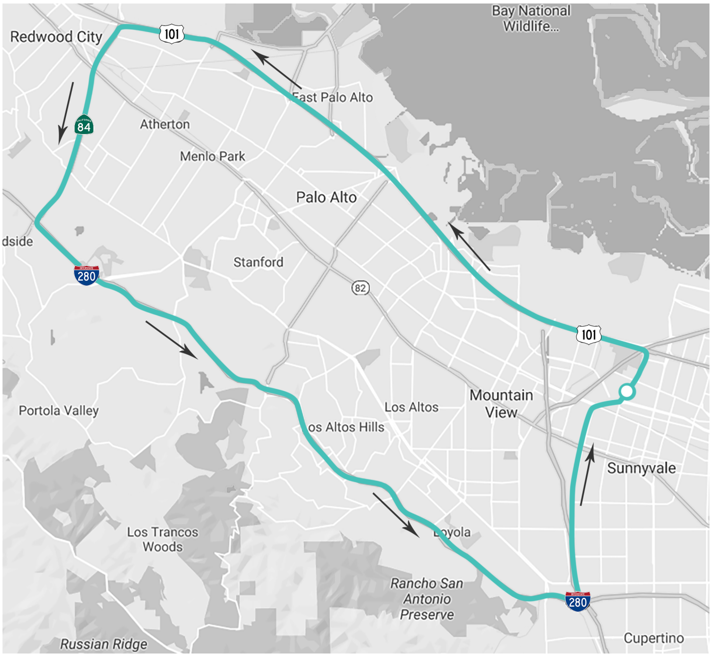

Figure 4.6: Route for the observation study in the San Francisco Bay area.

Participants

The study involved 20 participants, 11 females and 9 males, whose ages ranged from 22 to 62 years (Mean=42, SD=14). They were recruited and reimbursed through a local agency, which received screener and exclusion criteria. All participants had to be holders of a valid drivers' license, drive a car which was equipped with Common Cruise Control (Driver Assistance System which maintains road speed at a set point) and an automatic gearbox. All participants were frequent drivers and all but one commuted to work by car on a daily basis. Seven of the participants commuted less than 30 minutes, nine participants between 30 minutes and one hour, and three participants drove more than one hour to work, each way. None of the participants had jobs related to the car or tech industry, with education and health care being the most common occupation sectors, in addition to construction, social work, retail and accounting.

Analysis

From the transcribed material, statements where participants described their understanding of the two different systems were extracted. In the next step, a thematic analysis was conducted using an inductive coding approach (cf. Boyatzis, 1998). During this phase the data was coded and collated into categories for each function. Within each category, topics relating to each of the functions as well as new insights were identified and combined into themes, describing the factors that were judged to influence the users' understanding of the systems. The analysis resulted in the identification of four factors: Preconceptions, Perceived Usefulness, Perceived Control, and Trust. All interviews were carefully transcribed verbatim, coded and analysed using NVivo 12 software.

4.3.3 Key Findings

The key findings of this study concentrate on how users understand different driving automation systems, specifically a Level 2 partial automation and a Level 4 high automation system.

Preconceptions

Before the driving sessions, the participants were asked about their expectations of a highly automated system. Overall, there was consensus among all participants that it would have a positive impact on their stress levels because they believed they could hand over the driving task to the vehicle in situations where they did not want to drive themselves. Hence, one of the most commonly mentioned situations was during commutes to and from work, especially during rush hour and congested traffic. Equally, the participants expected to be able to use the system during long drives on the highway, for example when travelling for longer periods. In all cases, the participants expected to be relieved of mental workload and the driving task during demanding traffic situations, and to get free time during long drives to relax or engage with passengers.

Perceived Usefulness

The Level 2 system was believed to be especially useful on longer drives when the traffic flows smoothly. The participants felt that the system made driving easier as it relieved them of physical and mental workload such as accelerating, braking and keeping a set distance to other vehicles. Furthermore, the participants referred to the system as an extra set of eyes and valued its support in keeping to the speed limits. However, some participants were uncertain about what driving assistance the system offered and were not satisfied with the system's performance as they felt that too much interaction was needed (for instance irritation that they continuously had to be engaged in monitoring and steering) and therefore did not see how they benefited from using it.
The Level 4 system was believed to be mostly useful on highways and in congested traffic. Furthermore, participants stated that it would be a useful function to use when they were tired or were not properly attentive due to their personal condition. The participants believed that the system reduced stress and helped them relax. Moreover, some participants indicated that the system would enable them to be more efficient or socialize with passengers, for example to plan the day, write emails and make calls, as they would be freed from the driving task and could engage in other things. However, it was mostly highlighted that having a driving automation system was perceived to contribute to safer driving and therefore believed to result in fewer traffic accidents.

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Perceived Control

Control was a factor that was frequently discussed by the participants when talking about their understanding of the systems. When using the Level 2 system, participants regarded the driver as being in control of the vehicle, or the driver was perceived as receiving assistance from, or sharing control with, the vehicle. As a consequence of the assumed shared

control, several participants revealed confusion regarding control allocation when the system was active, resulting in ambiguity about what their responsibility actually was. Some participants felt that they could disengage since the Level 2 system does not take over the driving task but merely assists the driver.
The Level 4 system was described as taking over control completely from the driver, requiring very little human input and causing the driver to feel like a passenger in the car. Nonetheless, apart from a few participants who felt insecure about how much responsibility they could defer to the vehicle, most did not feel like they were out of control because they could take over the driving at any time by deactivating the system. However, many participants still felt responsible for supervising the vehicle as they had activated the system and were sitting in the driver's seat.
Ultimately, control allocation during the different driving modes caused confusion, especially when driving with the Level 2 system. Such confusion is risky as it can cause problems concerning the driver's understanding of how much responsibility they have to take with regard to the driving task and when they are free to disengage.

Trust

During the interview, the participants were asked if they felt they could trust the systems they had experienced. Initially the participants felt that they were insecure about the systems and did not trust them, but all the participants noted that over time they built a certain level of trust in the system and willingness to continue using it. Initial uncertainties were explained by lack of knowledge about the abilities of the systems, since all the participants only ever experienced a Level 1 system, that is to say Common Cruise Control. Therefore, one of the reasons they built trust in the system was that they observed different situations that the vehicle was able to handle, for example adjusting their speed to that of the vehicle ahead,or reacting to merging traffic. Other factors that were mentioned were consistency and car behaviour, since these were interpreted as though the vehicle had situational awareness similar to that of a human driver, being able to anticipate the behaviour of other road users and therefore being regarded as more trustworthy than a system that only reacts. Finally, the vehicle brand was named several times as a trustworthy brand with a reputation for safe vehicles, which prompted the participants to put their trust in the unknown systems.
It is noteworthy that there are several factors which influence trust, but even after a short period of use the participants built trust in the system, showing that consistent and transparent behaviour is a deciding factor in the initial stages of usage, leading up to continued usage of the systems.

4.4 Conclusions From the Studies

This thesis aims to answer the question of which factors influence the driver's perception of a driving automation system. In order to be able to address the research question three topics were defined, which led the design of the three conducted studies. The studies aimed to answer the following questions: 1. When drivers use driving automation systems, 2. Their motivation to use or not use the systems, and 3. Factors influencing their understanding of the systems. The following section concludes the summary of the studies by discussing the results in light of the three topics.

4.4.1 Situational Usage

A first aim was to explore in what situations and under which circumstances drivers tend to use driving automation systems. Different contextual factors were mentioned by the drivers in connection with system performance and perceived usefulness in the relevant situations. Study 1 addresses this question under the spotlight of cultural identity and how this influences situational usage. The results show a considerable overlap between the different countries, and only small differences between the various cultures, and this is assumed to be able to be traced back to infrastructural differences (reported in Paper A). Further insights on situational usage of the systems were revealed in Studies 2 and 3, even though this was not aimed for initially. The studies indicated the effects of driving context on system usage and found that drivers had different preferences regarding when to use the systems as a consequence of issues such as traffic conditions, road types, trip types and weather conditions (details are reported in Paper B). Moreover, different driving contexts were mentioned in

connection with the perceived benefits, ranging from traffic conditions and road types, to personal condition or simply the need to free up time by handing over the driving task to the vehicle, and Papers D and E elaborated on this aspect.
In summary, the factors influencing when drivers utilize driving automation systems are road types, traffic conditions, weather and daytime conditions, as well as the personal condition of the driver.

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4.4.2 Motivation of Usage

Based on the results of the first study, the aim was to understand how drivers motivate their usage of driving automation systems. Study 2 and Study 3 delivered insights on how driving automation system usage is affected by the driving context. The drivers' explanations varied depending on their experiences with the systems and led to the identification of several factors and user groups.
The results showed that depending on the driving context, for example weather conditions or road types, system performance is perceived differently by drivers and that this in turn affected their usage of the systems. The effects of driving context on usage of Level 1 and Level 2 driving automation systems were discussed in detail in Paper B. Another interesting finding that resulted from Studies 2 and 3 was that trip type, that is to say long vs. short trips, played a major role in whether or not the drivers would activate the systems. In addition, the quantitative data from Study 2 enabled the identification of different user groups that could be explained through preconceptions and the trust the drivers had in the

systems. Insights into driver preferences and perceived usefulness of the driving automation systems, specifically regarding Level 2 and Level 4 systems, were found in Study 3. Overall, the drivers explained that both systems would enable relaxation and reduce stress by reducing the mental workload. Besides enhanced comfort through use of the systems, safety was another significant factor on which the drivers all agreed (an overview can be found in Paper E). These results, however, were also related to the different contexts and the system's performance, as was found in the subsequent interviews during both Study 2 and Study 3.
In summary, the drivers' explanations of their usage strategies were linked primarily to contextual factors, which interplay with system performance. The perceived system performance in different situations determines if and when drivers perceive the systems as useful and are willing to engage with them. These findings revealed a threefold interrelation between driver, system and context.

4.4.3 Factors Influencing Understanding

The final aim was to identify the factors that affect the drivers' understanding in order to examine how their understanding is structured. Based on the drivers' explanations of their usage strategies, it was found that their understanding is in a threefold interrelation between the driver, the vehicle and the context, and that this understanding is composed of several different aspects. This in turn demonstrates that there are clear connections between their understanding of the system and the application of that perception. Study 2 revealed that

driver understanding is influenced by preconceptions about the system as well as perceived system performance and usefulness, which leads to different levels of trust. Furthermore, it was found that previous experiences, for instance supervised learning process vs. learning by trying on their own, played an important role in the drivers' understanding of the systems and the developed usage strategies. Another important focal point from Study 2 was that driver perception of the system does not simply change over time but needs to be challenged through new experiences, otherwise their mental model of the system and the interaction will not change. These results were discussed in detail in Paper C. The results of Study 3 added further insights, showing that in addition to preconceptions, perceived usefulness and perceived control of a system are also relevant for the driver's understanding of their responsibility over the driving task in a vehicle that offers multiple levels of automation, more specifically Level 2 and Level 4. It was found that perceived control had an influence on the driver's mode awareness and the way this affects how the driver understands his or her responsibility over the driving task, and the system's limitations. These insights were discussed in Papers D and F. Based on these results, aspects describing driver understanding of a vehicle with multiple driving modes were presented in Paper D, proposing a layered structure which explained the interrelations between the driver, the vehicle and the context and highlighting which different aspects are inherent in that understanding. Further, Study 3 indicated that system performance, more specifically factors such as the car's driving behaviour, are an important influence on how drivers make sense of their interaction with driving automation.

In summary, the findings from Study 2 and Study 3 revealed that the drivers' understanding is based on their preconceptions and their experience and perception during usage of the systems, which creates the basis for understanding.

CHAPTER 5

Perception Shapes Understanding

CHAPTER 5

Perception Shapes Understanding

This chapter presents the cross-study analysis of the findings from the presented studies, answering the research question. Moreover, it presents additional insights that emerged during the analysis, resulting in a unified descriptive model that can guide the design of driving automation systems.

5.1 Synthesised Findings

A number of recurring aspects describing users' understanding of what driving automation can do and how users perceive their interaction with these systems were identified in the cross-study analysis of Study 1, Study 2 and Study 3. The cross-study analysis resulted in a comprehensive overview of aspects that shape driver understanding of a driving automation system. Further, a more in-depth analysis revealed six factors that did not explain how drivers understand driving automation, but rather how they influence the driver's perception of driving automation during usage. The findings show that users of such systems, independent of the level of automation, talked about the driving modes by referring to different elements: the Context, the Vehicle, and the Driver. In addition, eleven recurring aspects were discerned in the thematic analysis: Driving Context, Personal Condition, Vehicle Operations, Comfort, Safety, Abilities, Limitations, Driver Tasks, Attentional Demand, Engagement with other Tasks, and Control. The identified aspects, including their sub-aspects, comprise the users' understanding of a driving automation system. A definition of each main aspect and its associated sub-aspects as well as categorization into the three different elements is presented in Table 5.1.

Table 5.1: Aspects that shape user understanding of a driving automation system.

Element	Aspect		Sub-aspect	Description	Study
CONTEXT When can I use the systems?	Driving Context	When and where to use the system	Traffic Conditions	The traffic conditions needed for the system to be operational, e.g. density or speed of traffic	1, 2, 3
			Road Types	The road types that the system can operate on, e.g. freeways or urban streets	1, 2, 3
			Weather Conditions	The weather conditions under which the system is operational, e.g. sunny \& dry, snow, rain, slippery surface	1, 2
			Time of Day	Time of day the system is operational, e.g. daylight, night-time	1, 2
			Trip Type	Trip types on which the system is used, e.g. long or short trip, commute to work, leisure activities, travelling	2, 3
	Personal Condition	How the driver feels	Tired	The physical and mental shape the driver is in, e.g. tired, less attentive, bored	1, 2, 3
			Bored		
VEHICLE What does the vehicle do?	Vehicle Operations	What part of the driving task the vehicle performs		Driving task performed by the systems, e.g. accelerate, brake or steer	2, 3
	Comfort	How the vehicle supports the driver	Physical and Mental Relief	The activities with which the vehicle supports the driver, e.g. relaxation and stress relief	2, 3
			Stress Relief		2, 3
	Safety		Extra Set of Eyes	The enhanced safety the vehicle offers, e.g. sees when I am distracted, less aggressive driving by following the traffic flow	3
			Calmer Driving Style		2,3
	Abilities	What underlying abilities the vehicle has	Situational Awareness	The perceived abilities of the vehicle to perform the driving task, e.g. understanding traffic situations, seeing other road users	3
			Predictive Capabilities	The ability to predict traffic development and actions of other road users, e.g. other road user might pull in in front of the vehicle	3
			Environmental Awareness	Reading traffic and road signs, lanes	3
	Limitations	What the vehicle cannot do		The functional limitations of the system, e.g. not being able to switch lanes	2, 3
DRIVER What can I do?	Driver Tasks	What the driver can/needs to do	Interaction with Displays and Controls	The interaction needed from the driver in order to operate the system, e.g. how to activate the system or manipulate the interface	2, 3
			Operation of Vehicle	What the driver needs to do in order to operate the vehicle, e.g. accelerate, brake and steer	3
	Attentional Demand	How much attention the driver must pay to the driving activities		The attention needed from the driver for driving, and the information required from the vehicle	2, 3
	Engagement with other Tasks	What the driver can do when not driving	Relaxation	The possibility to engage with other tasks than driving, e.g. reading, movies, emails, chatting with passengers	2, 3
			Productivity		3
			Socializing		3
	Control	Who is in charge of the driving	Responsibility	The allocation of control, i.e. who is in charge of the driving task, e.g. shared control or vehicle taking over control	2, 3
			Authority		2, 3
			Mode Awareness		3

Analysis of the data from the three studies identified six factors that influence how drivers perceive driving automation during usage. The six factors are Preconceptions, Perceived Usefulness, Previous Experiences, Trust System Performance, and Driving Behaviour, and they are also split into different aspects. These factors together with their aspects describe how a driver perceives driving automation in the moment, which in turn builds up to an understanding. The factors are presented in Table 5.2.

Table 5.2: Factors influencing the driver's perception of a driving automation system during usage.

Factor	Description	Aspect	Study
	Top-Down Processing Factors (Goal-Driven)		
Preconceptions	Mental model of the vehicle's capabilities, based on expectations	Situational Awareness	2, 3
		Predictive Capabilities	2, 3
		Environmental Awareness, e.g. reading traffic signs	2, 3
		Stress Relief	2, 3
Perceived Usefulness	The benefits the driver expects to gain from using the system	Driving Support	2, 3
		Enhanced Safety	2, 3
		Free Time	2, 3
Previous Experiences	How experienced situations and learning process influence understanding	Positive/Negative Experiences	2
		Learning Under Supervision	2
Trust	Level of trust the driver has in the system's capabilities	No Trust - "The Sceptic"	2
		Appropriate Trust - "The Conscious"	2
		Over-Trust - "The Enthusiast"	2
	Distinction between situations when the driver trusts the vehicle	Situational Trust	2
	Bottom-Up processing Factors (Conceptually Driven)		
System Performance	The execution of system functionality and how the driver perceives the system's reliability	Consistency	2
		Transparency	2, 3
Driving Behaviour	The vehicle motion that the driver feels and perceives	"Drives like me"	2, 3

The identified factors are split further into two groups: bottom-up processing factors and top-down processing factors. Preconceptions, Perceived Usefulness, Previous Experiences, and Trust fall into the category of the Top-Down processing factors, as these constitute contextual information, and can therefore be regarded as the perceptual set (cf. APA Dictionary of Psychology, 2020b). The perceptual set refers to the tendency to perceive objects or situations from a particular frame of reference. Existing schemas, mental frameworks, and concepts often guide perceptual sets. In top-down processing, perceptions begin with the most general and move toward the more specific. Such perceptions are heavily influenced by expectations and prior knowledge, such as schemas and mental models. In the case of a driver interacting with an automated driving system, the driver's perception will be influenced by preconceptions, perceived usefulness, previous experiences and the trust in

the system. Thus, the driver's understanding of the system is shaped by what they expect to perceive.
The System Performance and Driving Behaviour factors are categorized as bottom-up processing factors as they refer to sensory information in terms of environmental stimuli and occur in real time. The system performance and driving behaviour of the vehicle are both perceived in the moment through different sensory channels – visual, auditory and haptic input.
One important parameter to notice about perception with regard to driving automation systems is that everything is situational. The context or circumstances in which an event or situation is perceived influences what the driver expects in that particular situation, and the way the driver will assess interaction with the system. For example, during analysis of the three studies it became apparent that trust in the system was situational for the drivers. Depending on the particular driving context with which they were presented and the system performance during use in that context, the drivers showed more or less trust and were more or less inclined to use the systems – for example, different road types and weather conditions cause perceivably less stable or comfortable system performance so the drivers preferred to drive themselves.

5.2 The Process of How Perception Shapes Understanding

The proposed categorization of the identified aspects in Table 4 shows how user understanding of the systems is shaped by a layered structure, where the different layers interplay with each other and influence the user's interaction with the system (Figure 5.1). The findings from the cross-study analysis imply a continuous consideration of interdependencies between the Context (Conditions), the Vehicle (Performance), and the Driver (Responsibility). At the highest level of the structure is the driving context, which affects how the driver perceives the vehicle's performance, which in turn determines how the driver perceives their responsibility. If the driver understands who is in charge of the driving task during interaction with each different driving mode, this will in turn shape the driver's understanding of how and when they can use the driving automation.

Based on the three main elements that comprise the user's understanding, three questions were identified that guide the users: 1. When can I use the system? 2. What does the vehicle do? and 3. What can I do? While the user is guided by these three questions, their understanding of the driving modes the vehicle offers is ultimately shaped by the different aspects presented in Table 5.1.

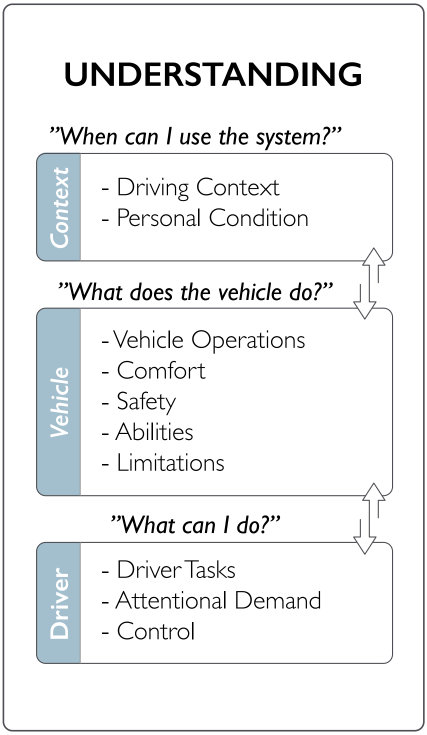

Figure 5.1: Conceptual Model of Drivers' Understanding of the Driving Automation.

Bearing in mind that the illustrated structure in Figure 5.1 is the basis of user understanding of driving automation, Figure 5.2 represents the top-down and bottom-up process and shows how the perception of driving automation during usage is constructed.
On the right side of the illustration, a similar structure to the model of users' understanding of how the driving automation works - the mental representation - is depicted.
However, this structure represents the user's perception of the driving automation system at the moment of usage.Therefore, the questions which guide the user's interaction with the system in the moment (now) are:

1. Can I use the system (now)?
2. What is the vehicle doing (now)?
3. What am I supposed to do (now)?

On the left side of the illustration the top-down and bottom-up processes are depicted and show how they influence the user's perception in the moment of usage. The perceptual sets (top-down) are in a constant feedback process with the perception of the system in the 'now' and are thus updated. This could mean that the perceived usefulness the driver experiences or the trust the driver has in the system can change, according to the experiences gained throughout the usage period. The sensory information, (bottom-up) on the other hand, directly influences the driver's perception of the driving automation. For example, unstable system performance on country roads with many bends and curves can give the driver information about the limitations of the system, which will update the driver's perception of the systems and influence the driver's usage strategies.

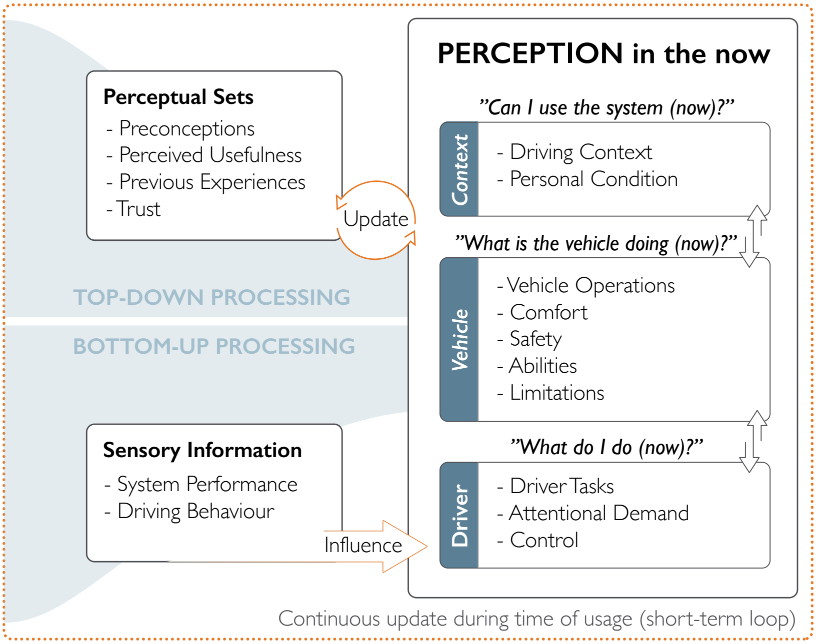

Figure 5.2: Model of how top-down and bottom-up processes influence perception of driving automation during usage.

Collectively, these conceptual models constitute the building blocks of a process and explain how a user perceives a driving automation system during usage and identify which factors influence that perception (Figure 5.3).

The flow of the process can be split into three parts:

1. General understanding: This block of the process represents the mental representation the user has of the system's characteristics and how to interact with it. It includes all the aspects and elements that make up the user's understanding and can be regarded as the baseline element from which all interaction starts.
2. Perception during use: This block represents the user's mental representation of the system during usage and shows how the interaction is influenced through the Perceptual Sets and Sensory Information they receive during driving. This block happens in real time and during engagement with the driving automation system, which means there is a continuous update (short-term loop) of the perception and therefore of the user's understanding of the system and how to interact with it.
3. Shaping understanding: The last part of the process is a long-term loop, which binds the two parts together. Perception of the system in the 'now' is continuously fed back to the users' understanding, causing them to update their understanding based on what they perceive during usage of the driving automation system.

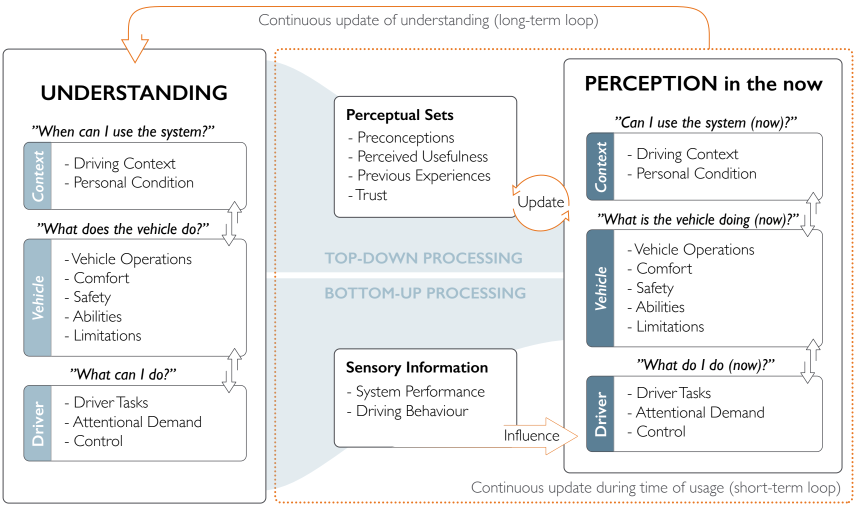

Figure 5.3: Unified Descriptive Model of Perception and Understanding (UMPU).

The whole process works through a feedback loop, where the outputs of the users' perception (the perception in the 'now'), are circled back and used as input to update understanding of the driving automation system. However, the factors Preconceptions, Perceived Usefulness, Previous Experiences, Trust, System Performance and Driving Behaviour of the Vehicle will influence user perception of the system and can cause either better understanding of the system and appropriate use or misinterpretation and as a consequence misuse.

CHAPTER 6

Discussion

CHAPTER 6

Discussion

This work aimed to investigate which factors influence the driver's perception of driving automation systems. By answering the research question, this thesis makes a theoretical and a practical contribution. In this chapter, this contribution is contrasted with existing research, and design implications are discussed.

6.1 Theoretical Contribution

The main theoretical contribution of this thesis is the unification of aspects that shape a driver's understanding of a driving automation system into a conceptual model and, building on this, a unified descriptive model of the process that shows how this understanding is shaped through everything that the driver perceives at the moment of use.

Earlier research took into account different factors that influence the driver's usage of driving automation systems. Beggatio and Krems (2013), for example, investigated whether the driver's mental model of their interaction with ACC changes when used continuously in the same situation and the way this affects the trust a driver has in the system. They found that negative experiences directly affected trust. Larsson (2012) discussed how the driver's understanding of system capabilities and limitations can lead to potential misuse in different driving contexts where the systems are not able to perform reliably. The described limitations in different driving contexts have been investigated on several occasions, and it has been found that driving behaviour and use of the systems in different contexts such as traffic, road and weather conditions, depend largely on driver understanding of /what?/(e.g. Liang et al., 2016; Ahlström et al., 2018; Ahmed and Ghasemzadeh, 2019; Papazikou et

al., 2017; Zhai et al., 2018). In another research stream, Wilson et al. (2007) found that perceived usefulness and safety benefits were connected to system performance and users' learning about system capabilities and limitations. Other studies further reported increased safety effects when driving with ACC (Jagtman & Wiersma, 2003; Ervin et al., 2005; Jamson, 2013), as well as a reduced workload, leading to a less stressful driving experience (Strand et al., 2014, Sullivan et al., 2017).
However, to the author's knowledge, so far there is no research that has provided as extensive an overview of different aspects, the way they relate to and influence each other, or an overview of how the identified aspects reflect a driver's perception and consequent understanding of a vehicle that offers multiple automation levels. So far, presented research has been conducted in separate silos, rarely relating to each other or combining the different aspects into a more comprehensive understanding of the driver's perception of driving automation.
In addition to the overview of the aspects describing user understanding, factors influencing the user's perception and consequent understanding were identified and presented in a unified descriptive model (UMPU). The benefit of this unified descriptive model is that it provides a framework that supports a systematic approach when designing for driving automation systems.

6.2 Perception Creates Reality

Chapter 5 offered an overview of the aspects and factors that shape the driver's understanding and influence their perception of driving automation systems. Further, a unified descriptive model (Figure 5.3) was presented that shows how the perception of a driving automation system shapes the driver's understanding.
After identification of the aspects that shape understanding and factors that influence perception of driving automation systems, and their theoretical basis, unification into a combined model was possible without encountering any conflicts between the building blocks. The UMPU was tested and discussed in thought experiments with colleagues knowledgeable in the field of driving automation, and through that feedback iteratively refined until the current representation was achieved.
The unified model represents two important parts of the process of how perception influences understanding. The first part of the model is the conceptual model of the driver's understanding of driving automation systems. The proposed model and categorization of aspects show that drivers do not understand driving automation systems, or levels of automation, in terms of how the systems are described in the existing taxonomies, such as SAE (2018). Rather, the findings imply a continuous consideration of the interrelation between the Context, the Vehicle and the Driver, and more importantly, the associated aspects. The suggested layered structure (see Figure 12) further suggests interdependencies where all layers are in interplay with each other and influence the user's interaction with the system, based on their understanding. With the assumption that drivers understand driving automation this way, and consequently interact with it based on the posed questions, it could be useful to represent possible interaction and introduce the system accordingly to the driver.
The second part of the unified model – the combined process of top-down and bottom-up

information processing or apperception (Saarilouma, 2003) – is illustrated, showing how this influences the driver's perception of the driving automation system during time of use. This step is relevant as it mirrors the driver's understanding of the system. However, the driver's perception of the system is influenced by perceptual sets (Preconceptions, Perceived Usefulness, Previous Experiences, Trust) and sensory information (System Performance, Driving Behaviour). The System Performance and Driving Behaviour of the vehicle can be considered feedback that the drivers perceive from the vehicle, for example vehicle motion, stiffness of steering wheel, driving style. Therefore, this determines their consequent understanding of the driving automation and thus their interaction with the systems.
Altogether, the aspects that shape the driver's understanding are thoroughly covered by the empirical evidence. The fact that the aspects that shape driver understanding were identified in three different studies, with different user groups and conducted in different markets, all converge into one coherent overview speaks for the validity of the results. However, the way the driver's understanding is influenced in detail is still uncertain. A closer look at the factors influencing the driver's perception and the model reveals that certain factors need deeper investigation. For example, system performance and driving behaviour are mentioned throughout Study 2 and Study 3. Although it is clear that these factors influence the driver through a bottom-up process, the true nature of these phenomena is not yet understood. Furthermore, the factors identified as part of the perceptual set are also largely unexplored regarding the perception of driving automation systems. The studies conducted here give insights into how preconceptions, previous experiences and trust affect driver understanding of and interaction with a driving automation system. However, deeper knowledge about how exactly these factors shape that understanding are still unexplored.

In summary, the UMPU posits that in order to design driving automation systems that are easy to use and that support the driver, one has to look at the driver's understanding as more than just a task-allocation issue, as suggested in current taxonomies. Due regard must be paid to the fact that in addition to the capabilities and limitations of the system, aspects such as the conditions during which the system can be used and the driver's responsibility in each situation must also be made abundantly clear. This requires that interrelations between the different elements and aspects have to be specifically designed for. Furthermore, the factors influencing perception also have to be considered during the design of the systems. Even though one might not be able to design directly for the identified factors, designers have to bear in mind that the user's perception of the systems is a key factor.
Therefore, when developing driving automation systems, one has to consider that the driver perceives more than just what the system does and what he or she has to do. The driver's perception during usage is influenced by several factors and processes, and the way they understand the systems is shaped through different aspects, which ultimately forms their reality of the systems. This means that designers' and developers' understanding of the system, its limitations, capabilities and feedback may not be perceived in the same way by the end-user. The driver's understanding is shaped through different and individual experiences, which influence how direct (sensory information) and indirect (perceptual sets) system behaviours and responses are interpreted and understood. Thus, when designing driving automation systems, one has to bear in mind that there are factors that influence the driver's perception and consequent understanding of the systems – perception creates reality.

6.3 Turning the Model into a Tool for Designers

At the heart of this thesis was the aim of generating knowledge about driver perception and consequent understanding of driving automation systems. Subsequent questions posed were: When do drivers use driving automation systems? Why do they use them in certain situations? How do drivers motivate their usage of driving automation systems? and What influences their understanding of the systems? These are typical examples of design problems, all of which need to be answered and approached through a user-centric perspective. A key problem for designers is finding an adequate framework, one that explains the problem area and guides design solutions. Therefore, it is of considerable importance that designers have tools to support their design decisions when developing solutions for driving automation systems so as to be able to improve system design and user experience. Lack of such support, or frameworks with faulty or inadequate representations, can lead to solutions that are not understood by the users or do not serve them. The unified descriptive model of perception and understanding (UMPU) presented in this thesis aims to support designers through theoretical and practical implications. On the one hand the model aims to explain how users understand driving automation systems and what factors influence their perception and consequent interaction with the systems. On the other hand, it aims to support design goals like improving system performance, user satisfaction, user understanding and so on.

The following paragraphs discuss design implications and how the model can be utilized for a user-centric design approach when developing driving automation systems.

Applying the model, designers can use the identified questions: 1. When can I use the systems? 2. What does the vehicle do? and 3. What can I do? and ask themselves the questions that the drivers will pose when interacting with the systems. Further, the model explains which factors influence the driver's perception in the moment and how they consequently understand interaction with a system. Thus, the model can be used as design support in order to cover the relevant elements that drivers identify during their interaction with a driving automation.

Tables 3 and 4 presented in Chapter 5.1 support design decisions by specifying what information the drivers need to be provided with in order to understand the system's capabilities and limitations, and also what influences that understanding. The aspects presented in Table 3 can be used as a basis for formulating design guidelines. For example, depending on the level of automation for which one designs, one can specify the design implications for the driving context by indicating when the system is available by means of direct feedback to the driver. Alternatively, if the system allows for engagement with other tasks and frees the driver from responsibility over the driving task then it should indicate this to the driver by unlocking access to the Internet or allowing the use of apps. Under consideration of the automation level, design implications should be formulated for all aspects presented in Table 3 as these are the aspects that the designers can directly address.

However, the factors influencing the driver's perception (presented in Table 4) cannot be addressed directly but need to be taken into consideration in other ways. For example, one cannot design for the Preconceptions a driver has about the system, but as Preconceptions represent the driver's mental model of the vehicle's capabilities based on expectations, expectations can be addressed and managed through targeted information distribution about the system prior to usage, such as through marketing channels and introduction videos.

Perceived Usefulness can be addressed in a similar way. However, even though Previous Experiences and Trust cannot be addressed directly, one can design for the learning process for example by supporting the user with smart agents during initial usage, which can guide and create a positive experience, fostering trust and the right understanding about the system's capabilities and limitations. Paper C discusses in detail how trust and understanding are linked and reveals how a driver's perception needs to be challenged in order to overcome inadequate usage strategies and be able to fully understand the system's capabilities and limitations. Furthermore, aspects like System Performance and Driving Behaviour need to be considered even though these cannot be designed for directly. For example, System Performance includes execution of system functionality and the way drivers perceive system reliability, in other words Consistency and Transparency. It is important to note that System Performance is inherently linked to the Driving Behaviour of the vehicle. This factor is often overlooked when designing driving automation, it needs to be seen as an important part of how drivers make sense of the vehicle's intentions and should be considered as part of multi-modal interaction. During Study 3 it became evident that different driving styles signal to the driver how capable the vehicle is in handling the driving context, that is to say dense and complex traffic scenarios. This shows that this factor also influences the trust the driver has in the systems.

However, as discussed earlier, even though factors influencing user perception of driving automation systems could be identified, deeper knowledge about the implications is still missing. Nevertheless, the unified descriptive model underscores the need to consider the whole user journey, from initial touching points like first impressions of the systems and vehicle through marketing campaigns, which feed Preconceptions, to acquisition of the car and initial usage, when the perception is continuously influenced by factors such as Driving Behaviour. In summary, the model highlights the need for designers to take into account that the reality the driver perceives is a result of the intersection of a top-down (perceptual sets) and bottom-up (sensory information) process, which is a critical component when designing for driving automation systems. Therefore, the interrelations between the different aspects shaping driver understanding, as well as the interrelations between the factors influencing driver perception in the moment of usage, need to be considered early in the design process.

6.4 Reflections on the Approach

The methodological discussion is divided into four sections, one for each of the three studies and one including concluding remarks on the embedded mixed-methods study design chosen for this project.

6.4.1 Study 1 – International Online Survey

As there was little to no knowledge about when drivers prefer to use driving automation systems, it was decided to utilize an international online survey to gather data from end-users. Online surveys are a fast and cheap way to collect data from a large population, especially when targeting a unique set of respondents, despite geographical separation. The aim of Study 1 was to gain insights into when drivers use existing (Level 1 and Level 2) systems in different driving contexts and to understand if there are any correlations between use of one system in a situation and use of the other system in the same situation. The use of an online survey made it possible to reach a targeted group in larger numbers, and to include different countries. While the use of online surveys enabled access to a unique population, one limitation of this approach was that it was hard to more precisely target people who have vehicles equipped with both systems. As a result, only a relatively small sample size from the initial set of respondents remained for analysis. This points at another problem, which is self-reported data (Wright, 2005), and thus only the respondents' own assessment of their usage strategies. Furthermore, there is no guarantee that the respondents provided accurate demographic or other information about systems available in their cars, which in the case of driving automation systems is problematic since previous research shows that many drivers are not aware of the systems fitted to their cars (Viktorová & Sucha, 2018). In addition, interpretation of the data can be challenging as there is no means of reaching out to follow up on answers or gain further insights beyond questions posed in the questionnaire.

6.4.2 Study 2 – Naturalistic Driving Study with Subsequent In-Depth Interviews

Naturalistic Driving Studies enable the collection of sensory-based vehicle data (e.g. GPS data, data indicating traffic and road conditions, data about usage of apps and driving automation systems) over a relatively long period, in the natural driving context. Since the vehicle data is usually collected and processed through unobtrusive technologies, driver usage patterns can be monitored at all times and without disrupting their daily lives and natural environment (Fridman et al., 2019).

The use of a longitudinal mixed-methods design for Study 2 made it possible to collect a large set of data from 132 vehicles, enabling the identification of different user groups who applied different strategies when using driving automation systems (Level 1 and Level 2). The subsequent interviews, with drivers from the identified user groups, made validation and in-depth understanding of the collected sensory data possible, leading to a deeper understanding of situational usage of the systems and the motivations behind those choices. Furthermore, initially emerging usage patterns from Study 1 could be analysed in detail and points of interest followed up in the interviews, enabling a focused investigation of the drivers' motivation for usage and the factors influencing their understanding of the systems. Finally, the subsequent interviews within the different user groups enabled an in-depth investigation into the drivers' prior experiences and learning processes with the systems, which supported the generation of a number of aspects relevant for driver understanding of DAS.

However, one of the limitations of the study was that it was conducted with a vehicle pool comprised solely of Volvo car models and Volvo Cars employees. Even though only participants who were not involved in the development of driving automation were included in the study and invited to the interviews, one cannot exclude a bias towards the vehicles and their fitted systems. Furthermore, the ND study does not account for possible car sharing scenarios, and the absence of a driver recognition unit on board can lead to the problem where driving patterns from one user cannot be distinguished from those of another, which can obscure the data based on the amount of sharing. Even though this was covered through a screening process, the self-reported car-sharing habits can only be regarded with caution. Another limitation of the study is the different level of experience that the participants had with the two systems. While all participants had access to the vehicle that was part of the NDS for about 3 weeks, some participants had prior experience with the Level 1 and/or Level 2 systems, even though they were of different versions. However, previous experiences were not accounted for in the NDS study and could only be followed up during the in-depth interviews to assess learning experiences and knowledge levels. Another possible limitation of the study was that the participating vehicles accounted for 6 different vehicle models, which could influence the system performance and driving behaviour of the vehicle, for instance sedan vs. SUV. However, while there are indications of this, there is no clear data about the influence of vehicle type on perceived system performance.

6.4.3 Study 3 – Wizard of Oz Observation Study with Subsequent In-Depth Interviews

As the third study aimed to investigate driver understanding of a vehicle offering several levels of automation, a quasi-experimental study design utilizing a Wizard of Oz vehicle was implemented. The semi-controlled study design made it possible to account for a range of variables, such as the participants, driving route, and the tested driving automation systems (Level 2 and Level 4). However, even though the route and session hours were chosen carefully through collected traffic data, the quasi-experimental setup does not make it possible to control traffic conditions. This variable could therefore vary in density and exposure times for the different participants and is regarded as a possible limitation. Nevertheless, overall, all participants had similar exposure times and encountered the required traffic situations for the driving automation systems to be operational. With to the possibility of conducting a fully experimental setup, the use of simulators was discarded as a simulator study does not necessarily provide an accurate image of how drivers respond to real-world traffic and the encountered scenarios when using driving automation. A quasi-experimental design has the advantage that it holds higher external validity as it involves real-world interventions (Grabbe, 2015).

With regard to the sample, there was an even distribution between female and male participants, with a feasible distribution in age, as well as prior knowledge of Level 1 driving automation but not higher-level automation. In other words, it is an advantage for the study to conduct the experiment with first-time users as these will probably engage in more conscious reflections during the think-aloud procedures and thus provide better insights into how they build their understanding of the systems. However, a downside of this is also that first-time users can be very excited about experiencing a self-driving vehicle, which can cause a bias in their behaviour, also referred to as the 'Hawthorne Effect' (McCarney et al., 2007). This effect refers to the changed behaviour of individuals in response to their awareness of being observed – an undisputed factor in an observation study. However, as the results of Study 3 were comparable and also offered new insights into both user motivation to use driving automation systems and understanding of such systems, the implementation of a quasi-experimental mixed-methods study design can be regarded as successful. Certain aspects such as driving behaviour were admittedly mentioned as important factors for the driver's perception of the system, but there is only limited knowledge about the nature of this phenomenon. This phenomenon might need to be addressed through another, more controlled, setup in order to gain in-depth knowledge.

6.4.4 Concluding Remarks on the Research Approach

The facilitation of empirical studies is critical if one aims to understand the users of a product, and end-users should be viewed as a source of knowledge, innovation and adaptation (Hollnagel and Woods, 2005) when aiming to design and improve driving automation systems. Many research streams concerning the evaluation of driving automation systems are centred around simulator studies, and even though they offer valuable insights on use of the systems, the lack of realism leaves those results largely without validation and will not deliver true insights on users' usage strategies and perception, as these insights are obscured by a safety net that they would not have when driving in real-traffic (Larsson, 2013).

The pragmatic choice to conduct mixed-methods research made it possible to shed light on the driver's utilization, perception and consequent understanding of driving automation systems. The combination of quantitative and qualitative data provided a broader understanding of the topic than would have been possible through only one approach, as the data usually differs in nature but investigates various aspects of the same problem. The use of both qualitative and quantitative methods was further beneficial owing to the exploratory inductive character of the selected research approach. This is because it allowed the collection of initial quantitative data from the survey and the NDS on when and how drivers utilize driving automation systems. This in turn led to a more in-depth investigation through the use of qualitative methods to gain insights into drivers' reasoning and premised on those insights, the generation of knowledge about how they understand and perceive such systems.

CHAPTER 7

Conclusions and Further Research

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This chapter concludes the thesis by summarizing the findings and discussing further research opportunities.

7.1 Conclusions

The aim of this thesis was to identify factors that influence the driver's perception and consequent understanding of driving automation systems. During the course of the project, it became apparent that the driver's understanding appears to be organised in a layered structure consisting of a range of aspects that are influenced by the driver's perception through a combined top-down (perceptual sets) and bottom-up (sensory information) process.
Based on those findings the Unified descriptive Model of Perception and Understanding (UMPU) was developed and presented. The UMPU exemplifies how the driver's understanding is shaped through their perception and how the different elements, the Driver, the Vehicle and the Context, are in interplay with each other. It aims to support designers through theoretical and practical knowledge. On the one hand the model explains how users understand driving automation systems and what factors influence their perception, and consequently their interaction with the systems. On the other hand, it provides a framework supporting a systematic approach when designing driving automation systems from a user-centric perspective.
Applying the model, designers can use the identified questions 1. When can I use the systems? 2. What does the vehicle do? 3. What can I do? and ask themselves the questions the drivers will pose when interacting with the systems. By answering these questions,

designers can approach the development of driving automation systems from a user-centric perspective. Further, the model explains which factors influence the driver's perception of the system in the moment of usage and also how, by exemplifying the top-down and bottom-up information processing. Thus, the model can be used as design support in order to cover the relevant aspects that drivers identify during their interaction with driving automation. Furthermore, it highlights the interrelations between the different aspects that shape the driver's understanding, as well as the interrelations between the factors that influence the driver's perception in the moment of usage.

Altogether, the UMPU presented in this thesis supports designers in the design of driving automation systems through the lens of their users, by taking into account what influences their perception of driving automation and shapes their understanding. In conclusion, the UMPU can guide the development of driving automation systems by identifying driver needs when engaging with such systems, and can support the development of design guidelines from a user-centric perspective.

7.2 Further Research

Driving automation systems are becoming an integral part of future vehicles in order to meet safety goals and address traffic safety. Nevertheless, for the foreseeable future, driving automation will not fulfil the potential of fully automated driving so a driver needs to be in control at all times, or able to take back control when the driving automation system can no longer execute the driving task. Thus, a human-centric development approach will continue to be the key for the successful development of driving automation systems. The results presented in this thesis provided answers to the research question of how drivers perceive driving automation systems. However, it also spotlighted some research tracks that remain unexplored.

This thesis has investigated how drivers perceive driving automation systems and how this influences their consequent understanding. From the results it appears that understanding the system's behaviour and responses is of considerable importance. One recurring theme when drivers described the feedback they received from the systems related to the vehicle's driving behaviour. This is a largely unexplored topic, but there is research to suggest that vehicle behaviour supports user understanding and sense-making (Johansson et al., 2020). A mixed-methods approach pairing observations, experimental studies and interviews could be beneficial to address this gap in order to identify the relevant elements for an embodied interaction model.

Another important topic to investigate further is how the driver's mental model is developed and how the development of an appropriate mental model of vehicle automation can be supported. This links back to the system's behaviour and feedback, but also includes the driver's ability to predict future states and actions of the system. The research results presented in this thesis have shown that a driver's mental model of the driving automation system affects their use of the system, as well as perceived usefulness and learning process. Therefore, in-depth studies should be carried out to examine how drivers can be supported during the learning process in order to expand and enhance their understanding of driving automation. This could be achieved through various approaches such as driver training or

smart agents in the vehicle, as discussed in Paper B and Paper C.
Even though it was barely discussed in this thesis, the increased complexity of vehicles that offer multiple levels of automation places higher demands on drivers and their ability to process the information they perceive during usage, from the system and the vehicle. This increases the possibility of errors if the system's behaviour and feedback are ambiguous. This can lead to the development of an incorrect mental model, or errors during usage leading to automation surprises, more specifically to mode confusion. Mode confusion can occur when the system mode is falsely classified and an action is taken that would be appropriate for the assumed system state, but not the actual situation (Sarter et al., 1997). Literature differentiates between two types of mode awareness; 1. Awareness of the existence of different levels of automation and 2. Awareness of the currently active mode (Monk, 1986). Even though this phenomenon is known, it is largely unexplored in the automotive context. It is therefore of considerable importance to clarify mode awareness and driver responsibility for the driving task under different conditions and in different driving modes.
In summary, this research needs to be continued in order to address possible knowledge gaps regarding the driver's understanding of a driving automation system. The identified factors influencing the driver's perception and consequent understanding are the first steppingstones on the way to gaining insights into the processes behind it.

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